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Design and Analysis of Delta Wing Tilt Rotor UAV

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ABSTRACT :
A tilt rotor is an aircraft of a special kind, which possesses the characteristics of a helicopter and a fixed-wing airplane. However, there are a great number of important technical problems waiting for settlements. Of them, the flight control system might be a critical one. A tiltrotor aircraft comprising a pair of contra-rotating co-axial tiltable rotors on the longitudinal center line of the aircraft. The rotors may be tiltable sequentially and independently. They may be moveable between a lift position and a flight position in front of or behind the fuselage.In this paper we present a project aimed for the designing of a small scale Unmanned Aerial Vehicle (UAV) with Tiltrotor configuration (that uses two rotating rotors). he current paper describes the adopted design methodology, the mathematical and computational models created to represent the UAV, the physical components that constitute the UAV, and the results obtained so far. An unmanned aerial vehicle (UAV), also known as a remotely piloted aircraft (RPA) or unmanned aircraft, is a machine which functions either by the remote control of a navigator or pilot or autonomously. A UAV is defined as a powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry payload.India's requirement of these unmanned aerial vehicles (UAV) has become prior need for fighting in the northeast, against threat of terrorism, tension along the Pakistan border and its emerging role as a regional naval power and subsequent need for surveillance. The military wants to acquire at least 1,500 unmanned systems in the next 3-4 years, ranging from man-portable drones to high-altitude, long-endurance (HALE) vehicles.Indian military is using Israeli-built UAVs such as the Heron, Searcher Mk II and Harop from Israel Aerospace Industries (IAI). Till date India has mostly deployed medium-altitude, long-endurance (MALE) drones. While the country lags in deployment of UAVs, it wants to develop an integrated program. RUSTOM (English: Warrior) is a Medium Altitude Long Endurance Unmanned Aerial Vehicle (MALE UAV) being developed by DRDO for the three defence services. Indian scientists are still working on its further developments to meet the requirements. This report is basically a case study on the design, development, technology used, working of Rustom and their earlier predecessors. It also includes the advancements which are going to be installed in the upcoming RUSTOM-H, a unmanned combat aerial vehicle (UCAV).
Keywords *:* UCAV , HALE UAV , Stealth Technology ,UAS ,Rustom

I. INTRODUCTION :

An unmanned aerial vehicle (UAV), also known as a Unmanned aircraft System (UAS) or a remotely piloted aircraft (RPA) or unmanned aircraft, is a machine which functions either by the remote control of a navigator or pilot (called a Combat Systems Officer on UCAVs) or autonomously, that is, as a self-directing entity. Their largest use are within military applications. To distinguish UAVs from missiles, a UAV is defined as a "powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload".[1] Therefore, cruise missiles are not considered UAVs, because, like many other guided missiles, the vehicle itself is a weapon that is not reused, even though it is also unmanned and in some cases remotely guided.

There are a wide variety of UAV shapes, sizes, configurations, and characteristics. Historically, UAVs were simple drones[2] (remotely piloted aircraft), but autonomous control is increasingly being employed in UAVs. UAVs come in two varieties: some are controlled from a remote location (which may even be many thousands of kilometers away, on another continent), and others fly autonomously based on pre-programmed flight plans using more complex dynamic automation systems. Currently, military UAVs perform reconnaissance as well as attack missions.[3] While many successful drone attacks on militants have been reported, they have a reputation of being prone to collateral damage and/or erroneous targeting, as with many other weapon types.[2] UAVs are also used in a small but growing number of civil applications, such as firefighting or nonmilitary security work, such as surveillance of pipelines. UAVs are often preferred for missions that are too "dull, dirty, or dangerous" for manned aircraft.

1.1.MALE UAV :
Medium-Altitude Long-Endurance (MALE) refers to an Unmanned Aerial Vehicle (UAV) that flies at an altitude window of 10,000 to 30,000 feet for extended durations of time, typically 24 to 48 hours.
Some examples of MALE UAV systems are:

- Aeronautics Defense Dominator
- IAI Heron
- TAI Anka
- EADS Harfang (Licenced produced IAI Heron)
- MQ-1 Predator
- Scaled Composites Model 395
- Chengdu Pterodactyl I
- EADS Talarion

1.2. HALE UAV
The Global Observer high altitude long endurance UAV system is developed by Aerovironment for missions spanning over a week. This aircraft was designed to provide long dwelling stratospheric capability with global range and no latitude restrictions.Operating at these heights, the platforms provides 'near space' capability comparable to satellites, providing services such as persistent communications relay, including dedicated communications support and satellite link redundancy for other UAVs. The aircraft is designed for operations significantly longer than the current Global Hawk, carrying payloads of 400 to 1,000 lbs of payload to an altitude of 65,000 ft. where it will cover a 'footprint' of up to 600 mile in diameter.The High Altitude, Long Endurance mission profile was never meant to be used with manned platform, but is perfectly suited for unmanned systems. Only few manned aircraft are prepared to fly and operate at these altitudes. The thin air at the Tropopause limits the use of conventional engines, but opens new horizons for surveillance, communications and electronic eavesdropping activities.

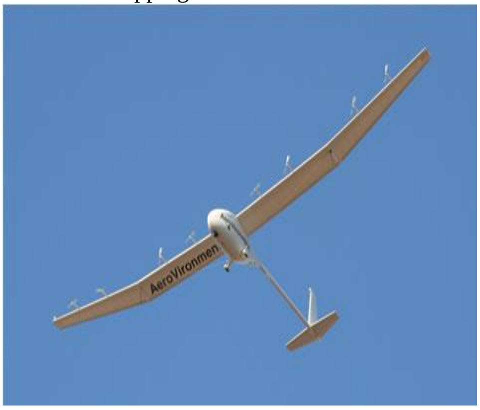


Fig-1 Aerovironment-a HALE UAV

After overcoming the technical obstacles, mission planners could benefit from unobstructed operations at altitudes well above civilian or military air traffic. At these altitudes, the atmosphere is calm, the thin air causes reduced drag, resulting in less energy required to maintain higher ground speed. Aircraft flying at these lofty altitudes are well above the jet stream and other high velocity currents, averaging 40 – 80 knots in speed, with peaks of up to 160 knots. These currents encountered at the high troposphere, at altitudes between 20,000 to 35,000 ft., usually affect the performance of aircraft operating at medium altitudes.

1.3. UCAV
Unmanned combat air vehicle (UCAV) or combat drone is an unmanned aerial vehicle (UAV) that is designed to deliver weapons (attack targets) – possibly with a great degree of autonomy.The elimination of the need for an onboard human crew in a combat aircraft that may be shot down over enemy territory has obvious advantages for personnel safety. In addition, much equipment necessary for a human pilot (such as the cockpit, flight controls, oxygen and ejection seat) can be omitted from an unmanned vehicle, resulting in a decrease in weight possibly allowing greater payloads, range and maneuverability.Current UCAV concepts call for an aircraft which would be able to operate autonomously. It will be programmed with route and target details, and conduct the mission without help from human controllers.

II. HISTORY :

The earliest attempt at a powered unmanned aerial vehicle was A. M. Low's "Aerial Target" of 1916.Nikola Tesla described a fleet of unmanned aerial combat vehicles in 1915. A number of remote-controlled airplane advances followed, including the Hewitt-Sperry Automatic Airplane, during and after World War I, including the first scale RPV (Remote Piloted Vehicle), developed by the film star and model airplane enthusiast Reginald Denny in 1935. More were made in the technology rush during the Second World War; these were used both to train antiaircraft gunners and to fly attack missions. Jet engines were applied after WW2, in such types as the Teledyne RyanFirebee I of 1951, while companies like Beechcraft also got in the game with their Model 1001 for the United States Navy in 1955. Nevertheless, they were little more than remote-controlled airplanes until the Vietnam Era.

2.1. UAV Classification
UAVs typically fall into one of six functional categories (although multi-role airframe platforms are becoming more prevalent):

1. Target and decoy – providing ground and aerial gunnery a target that simulates an enemy aircraft or missile
2. Reconnaissance – providing battlefield intelligence
3. Combat – providing attack capability for high-risk missions (see Unmanned combat air vehicle)
4. Logistics – UAVs specifically designed for cargo and logistics operation
5. Research and development – used to further develop UAV technologies to be integrated into field deployed UAV aircraft
6. Civil and Commercial UAVs – UAVs specifically designed for civil and commercial applications.

They can also be categorised in terms of range/altitude and the following has been advanced as relevant at such industry events as ParcAberporth Unmanned Systems forum:

- Handheld 2,000 ft (600 m) altitude, about 2 km range
- Close 5,000 ft (1,500 m) altitude, up to 10 km range

- NATO type 10,000 ft (3,000 m) altitude, up to 50 km range
- Tactical 18,000 ft (5,500 m) altitude, about 160 km range
- MALE (medium altitude, long endurance) up to 30,000 ft (9,000 m) and range over 200 km
- HALE (high altitude, long endurance) over 30,000 ft (9,100 m) and indefinite range
- HYPERSONIC high-speed, supersonic (Mach 1–5) or hypersonic (Mach 5+) 50,000 ft (15,200 m) or suborbital altitude, range over 200 km
- ORBITAL low earth orbit (Mach 25+)
- CIS Lunar Earth-Moon transfer
- CACGS Computer Assisted Carrier Guidance System for UAVs

The United States military employs a tier system for categorizing its UAVs.

2.2. Need/Cause for developing UAV

The birth of US UAVs (called RPVs at the time) began in 1959 when USAF officers, concerned about losing US pilots over hostile territory, began planning for the use of unmanned flights. This plan became intensified when Francis Gary Powers and his "secret" U-2 were shot down over the USSR in 1960. Within days, the highly classified UAV program was launched under the code name of "Red Wagon." The August 2 and August 4, 1964, clash in the Tonkin Gulf between naval units of the U.S. and North Vietnamese Navy initiated America's highly classified UAVs into their first combat missions of the Vietnam War. When the "Red Chinese" showed photographs of downed US UAVs via Wide World Photos, the official U.S. response was, "no comment." Only on February 26, 1973, during testimony before the US House Appropriations Committee, did the U.S. military officially confirm that they had been utilizing UAVs in Southeast Asia (Vietnam). While over 5,000 U.S. airmen had been killed and over 1,000 more were either missing in action (MIA), or captured (prisoners of war/POW); the USAF 100th Strategic Reconnaissance Wing had flown approximately 3,435 UAV missions during the war, at a cost of about 554 UAVs lost to all causes. In the words of USAF General George S. Brown, Commander, Air Force Systems Command in 1972, "The only reason we need (UAVs) is that we don't want to needlessly expend the man in the cockpit." Later that same year, General John C. Meyer, Commander in Chief, Strategic Air Command, stated, "we let the drone do the high-risk flying ... the loss rate is high, but we are willing to risk more of them ... they save lives!" During the 1973 Yom Kippur War, Syrian missile batteries in Lebanon caused heavy damage to Israeli fighter jets. As a result, Israel developed their first modern UAV. The images and radar decoying provided by these UAVs helped Israel to completely neutralize the Syrian air defenses at the start of the 1982 Lebanon War, resulting in no pilots downed. With the maturing and miniaturization of applicable technologies as seen in the 1980s and 1990s, interest in UAVs grew within the higher echelons of the US military. UAVs were seen to offer the possibility of cheaper, more capable fighting machines that could be used without risk to aircrews. Initial generations were primarily surveillance aircraft, but some were armed (such as the MQ-1 Predator, which utilized AGM-114 Hellfire air-to-ground missiles). An armed UAV is known as an unmanned combat air vehicle (UCAV)

2.3. Advantageous Features of unmanned aircraft(UA)

- supports a “fly and loiter” capability, in which the UA flies to a destination, where it then flies slowly in small circles to conserve fuel. The UA then uses its computer controlled imaging system, to maintain a watch on a particular target.
- is more environmentally friendly, since it:
  - requires less materials to build
  - uses less fuel per kilometre flown
  - creates less pollution (CO_2, for example) per kilometre flown
  - makes less noise in flight
  - is easier to dispose of at the end of its operational life
- can readily be stored, in large numbers if need be and is easily transported
- can fly in dangerous situations:
  - over active volcanoes
  - in the vicinity of, or, in the eye of, hurricanes and tornadoes
  - in adverse weather conditions, such as fog, heavy rain and thunderstorms
  - through poisonous gas clouds and over regions of high radioactivity
  - in challenging regions of the world: over the Arctic, over the Sahara desert…
- has unique flight capabilities:
  - can take off, fly and land, completely under computer control
  - can very precisely follow a flight path, enabling many UAVs to be used in close proximity, without concern for any mid-air collisions
  - can safely fly “low and slow,” following ground contours, at a height of only 20 m above ground level, for high resolution “drape” geomagnetic surveys
- can use high bandwidth Free Space Optics relay links between the UA performing the reconnaissance or survey work and the Ground Control System, to enable imagery and measurement data from several UAVs to be downloaded, as it is gathered, to a computer server, in a Network Centric system. The Network Centric model allows multiple users connected to the Internet to access data from the UA

2.4. Unmanned Aircraft (vs) Manned Aircraft :

Fig-2 Aerosonde UA &Cessna Skylane

$ 35,000 Unmanned Aircraft + 0 (no pilot) + 40 Kg fuel small: length = 2.02 m wingspan = 2.88 m	$ 268,750 plane + 85 Kg pilot + 273 Kg fuel large: length = 8.84 m wingspan = 10.97 m

costs less since:

- the Unmanned Aircraft itself is less expensive to purchase
- it has lower operational costs, because:
  - it has lower landing and parking fees and can often be landed on an unprepared strip
  - it uses less fuel per kilometre flown
  - no pilot's salary needs to be paid
- it can fly day and night, entirely under computer control
- there is less damage and consequences from any crash (lower insurance):
  - lower property damage in UA crash, due to the lower Kinetic Energy
  - no pilot injury, or, pilot death in an accident
- a lower upkeep, smaller airport, with low quality runway, can be used

2.5 Type of Existing UAV's Globally :

UAVs have been developed and deployed by many countries around the world. For a list of models by country. The use of unmanned aerial systems, however, is not limited to state powers: non-state actors can also build, buy and operate these combat vehicles. Most notably, Hezbollah has used drones to get past Israeli defenses, and in 2001 Al-Qaeda reportedly explored using drones to attack a conference of international leaders. The export of UAVs or technology capable of carrying a 500 kg payload at least 300 km is restricted in many countries by the Missile Technology Control Regime. At the center of the American military's continued UAV research is the MQ-X, which builds upon the capabilities of the Reaper and Predator drones. As currently conceived, the MQ-X would be a stealthier and faster fighter-plane sized UAV capable of any number of missions: high-performance surveillance; attack options, including retractable cannons and bomb or missile payloads; and cargo capacity. China has exhibited some UAV designs, but its ability to operate them is limited by the lack of high endurance domestic engines, satellite infrastructure and operational experience.

III. UAV FUNCTIONS

UAVs perform a wide variety of functions. The majority of these functions are some form of remote sensing; this is central to the reconnaissance role most UAVs fulfill. Less common UAV functions include interaction and transport

3.1.Remote sensing

UAV remote sensing functions include electromagnetic spectrum sensors, gamma ray sensors, biological sensors, and chemical sensors. A UAV's electromagnetic sensors typically include visual spectrum, infrared, or near infrared cameras as well as radar systems. Other electromagnetic wave detectors such as microwave and ultraviolet spectrum sensors may also be used, but are uncommon. Biological sensors are sensors capable of detecting the airborne presence of various microorganisms and other biological factors. Chemical sensors use laser spectroscopy to analyze the concentrations of each element in the air.

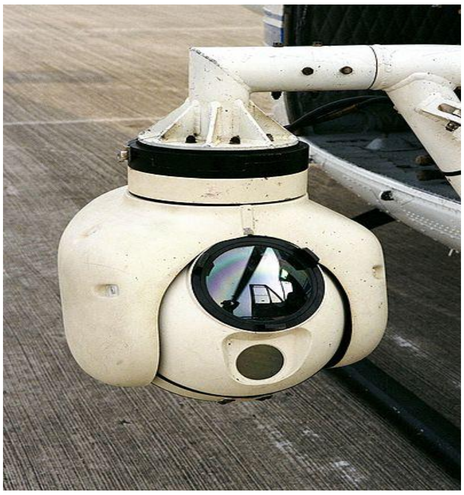


Figure 3.1: A forward looking infrared (FLIR) camera mounted on the side of an UAV

3.2. Commercial aerial surveillance

Aerial surveillance of large areas is made possible with low cost UAV systems. Surveillance applications include: livestock monitoring, wildfire mapping, pipeline security, home security, road patrol and anti-piracy. The trend for use of UAV technology in commercial aerial surveillance is expanding rapidly.

Figure 3.2: UAV for use in scientific, commercial and state applications

3.3. Oil, gas and mineral exploration and production

UAVs can be used to perform geophysical surveys, in particular geomagnetic surveys where the processed measurements of the differential Earth's magnetic field strength are used to calculate the nature of the underlying magnetic rock structure. A knowledge of the underlying rock structure helps trained geophysicists to predict the location of mineral deposits. The production side of oil and gas exploration and production entails the monitoring of the integrity of oil and gas pipelines and related installations. For above-ground pipelines, this monitoring activity could be performed using digital cameras mounted on one, or more, UAVs. The In View Unmanned Aircraft System is an example of a UAV developed for use in oil, gas and mineral exploration and production activities.

Figure 3.3 The RQ-7 Shadow is capable of delivering a 20 lb (9.1 kg) "Quick-MEDS"

3.4. Transport

UAVs can transport goods using various means based on the configuration of the UAV itself. Most payloads are stored in an internal payload bay somewhere in the airframe. For many helicopter configurations, external payloads can be tethered to the bottom of the airframe. With fixed wing UAVs, payloads can also be attached to the airframe, but aerodynamics of the aircraft with the payload must be assessed. For such situations, payloads are often enclosed in aerodynamic pods for transport.

Figure 3.4: Fulmar UAV, developed by Aerovision for civilian applications.

3.5. Scientific research

Unmanned aircraft are uniquely capable of penetrating areas which may be too dangerous for piloted craft. The National Oceanic and Atmospheric Administration (NOAA) began utilizing the Aerosonde unmanned aircraft system in 2006 as a hurricane hunter. AAI Corporation subsidiary Aerosonde Pvt Ltd. of Victoria (Australia), designs and manufactures the 35-pound system, which can fly into a hurricane and communicate near-real-time data directly to the National Hurricane Center in Florida. Beyond the standard barometric pressure and temperature data typically culled from manned hurricane hunters, the Aerosonde system provides measurements far closer to the water's surface than previously captured. Further applications for unmanned aircraft can be explored once solutions have been developed for their accommodation within national airspace, an issue currently under discussion by the Federal Aviation Administration. UAVSI, the UK manufacturer also produce a variant of their Vigilant light UAS (20 kg) designed specifically for scientific research in severe climates such as the Antarctic.

Figure 3.5: IAI Heron, an UAV developed by the Malat division of Israel Aerospace Industries

3.6. Armed attacks

MQ-1 Predator UAVs armed with Hellfire missiles are now used as platforms for hitting ground targets in sensitive areas. Armed Predators were first used in late 2001 from bases in Pakistanand Uzbekistan, mostly for hitting high profile individuals (terrorist leaders etc.) inside Afghanistan. Since then, there have been several reported cases of such attacks taking place in Pakistan, this time from Afghan-based Predators. The advantage of using an unmanned vehicle, rather than a manned aircraft, in such cases is to avoid a diplomatic embarrassment should the aircraft be shot down and the pilots captured, since the bombings took place in countries deemed friendly and without the official permission of those countries. A Predator based in a neighboring Arab country was used to kill suspected al-Qaeda terrorists inYemen on November 3, 2002. This marked the first use of an armed Predator as an attack aircraft outside of a theater of war such as Afghanistan. Questions have been raised about the accuracy of the targeting of UAVs. One issue with civilian casualties is the relative lack of discretion of the 100 lb (45 kg) Hellfire, which was designed to eliminate tanks and attack bunkers. Smaller weapons such as the Raytheon Griffin and Small Tactical Munition are being developed as a less indiscriminate alternative, and development is underway on the still smaller, US Navy-developed Spike missile. The payload-limited Predator A can also be armed with six Griffin missiles, as opposed to only two of the much-heavier Hellfires.

3.7. Search and rescue

Figure 3.6: A Bell Eagle Eye, offered to the US Coast Guard.

UAVs will likely play an increased role in search and rescue in the United States. This was demonstrated by the successful use of UAVs during the 2008 hurricanes that struck Louisiana and Texas.

For example, Predators, operating between 18,000–29,000 feet above sea level, performed search and rescue and damage assessment. Payloads carried were an optical sensor (which is a daytime and infra red camera) and a synthetic aperture radar. The Predator's SAR is a sophisticated all-weather sensor capable of providing photographic-like images through clouds, rain or fog, and in daytime or nighttime conditions; all in real-time. A concept of coherent change detection in SAR images allows for exceptional search and rescue ability: photos taken before and after the storm hits are compared and a computer highlights areas of damage

IV. UAV's REQUIREMENT FOR INDIA

India's need for unmanned aerial vehicles (UAVs) is growing, said military officials in New Delhi. The country's UAV requirement first became apparent after the 1999 conflict in Kargil. The UAVs became critical in the absence of airborne warning and control system aircraft in the Indian defense forces, and were used in the upper reaches of the northern Indian state of Jammu and Kashmir, where radar installation was impossible. The navy also relied on UAVs, said a senior Indian Navy official, and acquired six Heron medium-altitude, long-endurance UAV systems, which have been deployed on warships in the Arabian Sea for Pakistani naval activities

The Indian Defence Ministry is negotiating to buy 36 additional Herons from Israel at an estimated price of about $6.1 million a piece. The military wants to acquire at least 1,500 unmanned systems in the next 3-4 years, ranging from man-portable drones to high-altitude, long-endurance (HALE) vehicles. Besides the order for Herons last year, the

DefencMinistryhad invited bids from overseas companies to supply short-range UAVs. The letters inviting bids for 16 short-range UAVs for $87 million were sent in 2003 to Israel-based IAI Malat, Elbit and Aeronautics Defense Systems; Germany-based STN Atlas Electronik and EMTI; France-based CAC Systems; U.S.-based AAI and Freewing Aerial Robotics; South Africa-based Denel and ATE; Austria-based Schiebel and Vectra; Switzerland-based Swiss Aircraft and Systems; and the Russian government firm Rosoboron export. The procurement process is expected to be complete within two years.

V. PRESENTLY USING UAV'S IN INDIA

Indian military is using Israeli-built UAVs such as the Heron, Searcher Mk I, Searcher Mk II and Harop from Israel Aerospace Industries (IAI). Till date India has mostly deployed medium-altitude, long-endurance (MALE) drones. While the country lags in deployment of UAVs, it wants to develop an integrated program. RUSTOM (English: Warrior) is a Medium Altitude Long Endurance Unmanned Aerial Vehicle (MALE UAV) being developed by DRDO for the three defence services. Indian scientists are still working on its further developments to meet the requirements.

5.1. Proposal for RUSTOM

Indian Defence Ministry officials say the military has a requirement of more than 250 UAVs in addition to the Nishant and Lakshya developed by India's Defence Research and Development Organisation (DRDO). Earlier, rejection of Nishant by the Indian Army for use in the higher reaches of Jammu and Kashmir helped spur acquisition of Israeli UAVs.

Early this year, the DRDO also began limited production of the homegrown Nishant, said a senior DRDO scientist, after earlier problems were overcome.

The Indian Army ordered an initial 24 Nishants, developed by the Bangalore-based, state-owned Aeronautical Development Establishment, which functions under DRDO. Developed for battlefield surveillance, the Nishant project began in 1988 and was scheduled to be inducted into the Army by 1996-97.

A senior scientist with the Aeronautical Development Establishment said Nishant is capable of instantly providing battlefield intelligence to field commanders through data designed to survive electronic countermeasures.

Nishant has a range of at least 100 kilometers, and the 360-kilogram vehicle is designed for electronic intelligence and electro-optic reconnaissance for the Indian Army.

The other UAV, Lakshya, will be produced by state-owned Hindustan Aeronautics Ltd., Bangalore, which expects an order for 20 vehicles from the Indian defense forces, said Nalini Ranjan Mohanty, the company's chairman.

Lakshya is a turbojet aircraft capable of carrying a 350-kilogram payload 600 kilometers. Several indigenously developed payloads are available for UAV applications, such as electro-optic imaging, a laser ranging and designation system, and an airborne infrared target sensor.The Indian government has allowed the development of the Rustom MALE UAV project in association with a production agency cum development partner (PADP). The ADE officials indicated that the requests for proposals (RFP) would shortly be issued to four vendors which are the Tatas, Larsen and Toubro, Godrej and Hindustan Aeronautics Limited-Bharat Electronics (joint bid) who were chosen out of the 23 firms that responded.Currently, negotiations are underway between these companies and the three Indian armed forces since the private majors are looking for support and commitment from them before they start executing any development and production plans. This is because of the fact that the chosen PADP will also have a financial stake in the Rustom project. The Armed Forces would also be asked to take up a financial stake and the Indian government may have to guarantee that a specific number of Rustom UAVs will be bought. A prototype to validate the technology for the project has been built and the taxi trials has been completed.

- Rustom-1: tactical UAV with endurance of 12 hours
- Rustom-H: Larger UAV with flight endurance of 24 hours.
- Rustom-C: Armed version of the Rustom-H UAV.
- Rustom 1, a medium-altitude and long-endurance Unmanned Aerial Vehicle (UAV), developed by the Bangalore-based Aeronautical Development Establishment (ADE), was successfully test-flown here on Saturday.
- According to an official statement, Rustom 1 was flown from the Taneja Aerospace and Aviation airfield at Hosur near here. “The aircraft took off even in inclement weather conditions for a first flight, flew for 12 minutes and landed successfully, meeting all its objectives.”
- Surveillance aircraft
- A Defence Research Development Organisation (DRDO) spokesperson told The Hindu on Sunday that Rustom 1 followed the two other UAVs developed by the ADE — Lakshya and Nishant. While Lakshya — a drone that is remotely piloted by a ground control station — provides aerial sub-targets for live-fire training, Nishant is a surveillance aircraft primarily tasked with intelligence gathering over enemy territory

“Unlike the other UAVs, which used to have a free fall with parachutes after executing their tasks, Rustom will carry out copybook style landing,” the spokesperson said.

- “In the coming days Rustom can be used as unmanned combat aerial vehicle and also to carry war-heads,” the spokesperson said.
- The first full flight of Rustom 1 on Saturday was under the command of Lt. Col. V.S. Thapa of the Army, an experienced External Pilot for UAVs, who was positioned at the edge of the runway. “He controlled it without any difficulty throughout its flight, which included the pilot-assisted take-off flight in air and a copybook style landing,” the statement said.

Many auto features

- The aircraft has many auto features such as GPS controlled Way Point Navigation and Get U Home included even in its first flight, but will be exercised in subsequent flights.
- “The UAV has an endurance of 12 to 15 hours and can carry payloads up to 75 kg. It has an altitude ceiling of 25,000 feet. Such flights of UAVs remove the risk to human pilots when they have to fly them in hazardous zones,” the statement said.
- The data link system for this UAV was designed and developed by another DRDO laboratory called Defence Electronics Applications Laboratory (DEAL) situated in Dehra Dun. Its airframe is made by a private company called Zephyr situated in Coimbatore and most of its onboard systems are also manufactured by private industries in different parts of the country.

“This UAV can be used by all the three armed services of our country,” the statement

RUSTOM Unmanned Aerial Vehicle, Chitradurga, India

Rustom (English: Warrior) is a Medium Altitude Long Endurance Unmanned combat Aerial Vehicle (UCAV) being developed by DRDO for the three services, Indian Army, Indian Navy and the Indian Air Force of the Indian Armed Forces. Rustom's basic design is derived from the NAL light canard research aircraft (LCRA). The aircraft has been named after Rustom Damania, a former professor of IISc, Bangalore who died in 2001. DRDO decided to name the UAV after him because it is derived from National Aeronautical Laboratories’ light canard research aircraft (LCRA) developed under Rustom Damania’s leadership in the 1980s. The UAV will have structural changes and a new engine. Rustom will replace/supplement the Heron UAVs in service with the Indian armed forces.

Specifications

Maiden Flight - October,2010
Introduced -2012

General characteristics

- Crew: none
- Length: ()
- Wingspan: 20 m (65.616 ft)
- Height: ()
- Empty weight: 1,800 kg (3968.32 lbs)
- Powerplant: 1 × , ()

Performance

- Maximum speed: 225 km/h (139.81 mph)
- Range: 350 km ()
- Service ceiling: 35,000 ft (10,668 m
  - Variants
  - There will be three variants of the Rustom UAV.[11]
  - Rustom is a remote controlled, medium altitude and long endurance (MALE) unmanned aerial vehicle (UAV) being designed and manufactured by Aeronautical Development Establishment, a subsidiary of the Defence Research and Development Organisation, India, for the Indian Armed Forces.

- It is derived from its forerunner, the Light Canard Research Aircraft (LCRA) built by National Aerospace Laboratories (NAL).
- Flying at an altitude of 35,000ft, the Rustom captures real time imagery of the battlefield and transmits information to the ground control station (GCS) through a satellite communication datalink.
- **Rustom variations**

The Rustom has three variants: Rustom-1, Rustom-H and Rustom-C.The Rustom-1 is a standard model built for tactical surveillance. The variant took off for its maiden flight from Taneja Aerospace and Aviation (TAAL) airfield in May 2011. It has an endurance of 12 to 14 hours.

The Rustom-H will be larger than Rustom-1 and can fly for a maximum of 24 hours. It will be powered by two conventional wing mounted turboprop engines.

A military version of Rustom-H, the Rustom-C, will execute both combat and surveillance missions. It will carry a guided strike munitions on each wing.

Design specifications of the aircraft

"Flying at 35,000ft, the Rustom captures real time imagery of the battlefield."

The Rustom has been designed to carry out both military and commercial operations.

The 20m wide aerial vehicle can execute intelligence, surveillance and reconnaissance (ISR) missions even in the worst climatic conditions.

The aircraft can also perform border patrol, coast guard and maritime patrol operations.

Development phases

Rustom is being developed by the Indian Government in two phases to supersede the Heron UAVs currently in service with the Indian Armed Forces.Work on phase I includes transforming the LCRA into Rustom prototype and carrying out flight tests. The Rustom will be delivered to the customers during the second phase.DRDO has developed the prototype to validate the technologies for the Rustom project.The prototype took off for its first trial in September 2008. During the maiden flight in November 2009, it crashed due to incorrect judgement of altitude.The request for proposal (RFP) was issued to four companies: Tata Advance Systems, Larsen and Toubro, Godrej Precision Systems and Hindustan Aeronautics Limited (HAL)-Bharat Electronics Limited (BEL).The joint bid of HAL and BEL was selected for Rustom development. The HAL-BEL joint venture and ADE are the prime contractors involved in the project.The second maiden flight of the Rustom was successfully completed in October 2010. The UAV is scheduled to enter service in 2012. The Cabinet Committee on Security (CCS) approved INR10.54bn funding in March 2011 for developing a meliorated version of Rustom-1.

"It is also fitted with a directional satellite antenna on the top of centreline fuselage."

About INR1.156bn was earmarked for producing 15 aerial vehicles and the remaining INR0.384bn was earmarked to set up a dedicated aeronautical test range at Chitradurga, situated approximately 200km away from the city of Bangalore.

The Rustom features an all-modular composite airframe supplied by Zephyr. An electro-optic camera is installed beneath the front fuselage section to capture the battlefield imagery.It is also fitted with a directional satellite antenna on the top of centreline fuselage section to minimise jamming and to allow communications up to 350km range from the GCS.

Navigation

The Rustom can be operated either manually from the GCS or through autonomous mode using GPS based in-flight way point control. The vehicle is equipped with an automatic take-off and landing (ATOL) system to assist in automated safe landing when communication between the vehicle and GCS fails.

Sensors

The UAV is incorporated with electro-optic (EO), infra-red (IR) and electronic intelligence (ELINT) sensors.

Radar technology

The Rustom is equipped with synthetic aperture radar, maritime patrol radar, laser range finder, radar warning, traffic collision and avoidance system (TCAS), laser illuminator and communication intelligence (COMINT).

Ground control station

Processing, retrieving, storing and monitoring of the real time imagery or videos captured by the Rustom are carried out at the ground control station (GCS). Communication between the vehicle and the GCS is enabled through a line of sight (LOS) satellite communication (SATCOM) datalink.The Rustom can fly at a maximum speed of 225km/h. The range and service ceiling of the aircraft are 350km and 10,668m respectively.

<u>First Flight Test</u>

A subscale prototype/technology demonstrator of Rustom-1 made its maiden flight on November 16, 2009, at the Taneja Aerospace Air Field near Hosur.

After a successful flight the prototype crashed during landing because its engine was prematurely cut off as a result of the pilot misjudging the height.Despite the mishap, the state-owned Defence Research and Development Organisation stated: "The flight proved the functioning of a number of systems such as aerodynamics, redundant flight control, engine and datalink, which go a long way towards the development of a complex UAV."

At least 10 more test flights of the Rustom design are expected before the system can be taken up for production. The test work is being performed using a sub-scale version of the air vehicle (Rustom-I TD) with a 1.5 m (4.9 ft) wing span and an overall length of 3m.

<u>Second Flight Test</u>

The second test flight, on October 15, 2010 was fully successful. The UAV flew for 30 minutes at an altitude of 3,000 feet. The test was conducted in Hosur.

Rustom-1 sub scale prototype first flight on October 15, 2010

Free Flight

A successful flight test of Rustom1 UAV was conducted at around 12 noon on 21st May 2011. It was the second successful flight of "Rustom 1" being developed by the Aeronautical Development Establishment (ADE), a DRDO lab engaged in pioneering R&D work in the field of aeronautics. The "Rustom 1" has an endurance of 14 hrs. and altitude ceiling of 8000 meters. Rustom 1 has been achieved by converting a manned aircraft in to a UAV (Unmanned Aerial Vehicle) by removing pilot seat and making required electrical, mechanical and aerodynamic modifications.

First Flight of Rustom-1 Full Scale Prototype on 21 May 2011

A full scale prototype of Rustom-1 first flew around 12 noon on May 21, 2011.

Like the first and second test flights of the subscale prototype, the full scale prototype flew from the airfield of Taneja Aerospace (TAAL) located near Hosur. Many improvements have been carried outs since the last flight, in terms of piloting, landing, taxiing etc. The flight was a precursor to the flight with payloads as required by the Services.. Lt Col Thappa from the Army was the external pilot for total mission flight who had no difficulty for control of the vehicle.

Rustom-1 which has completed all test flights is likely to be used as a short-range UAV by the users. Among the proven capabilities include: (i) taxi take-off with automatic nose-wheel steering; (ii) extended pilot control for taking the platform to the centre of the runway; (iii) autopilot mode for the flights, including way-point navigation (WPN) and get-you-home features; (iv) redundant Flight Control System, hardware and software and (v) integrated C-Band data-link.These proven features have made Rustom-1 a UAV of its own, which the users (Army) are interested to use as a short-range platform

DRDO-ADE 'Rustom-I' and 'Rustom-H'

Type: Medium-Altitude Long-Endurance (MALE) UAV
Powerplant: 2 x 120hp 4-cylinder, 4-stroke Rotax 914 engines
Significant date: 2009
Spurred by the success of its Nishant UAV program, India's DRDO (Defence Research and Development Organisation), one of Asia's largest defence contractors and a leading aerospace manufacturer (headquartered in New Delhi) has embarked on an ambitious program to develop a long endurance and range UAV named Rustom through its ADE (Aeronautical Development Establishment) subsidiary, to replace the current Israeli Heron drones. Although it is not acknowledged officially, reliable sources claim that ADE is getting help from Israel's IAI on the Rustom program.With the Rustom MALE UAV project, DRDO intends to move away from traditional ways of developing products whereby laboratories under DRDO, like the ADE, develop and finalize the product and transfer technology to a production agency. In order to reduce the time to make the system operational, DRDO will follow a practice of concurrent engineering where initial design efforts also take into consideration production issues, with a production agency and development partner (PADP) identified from within the Indian industry who will have a stake in the program, participating in the development of the system right from the design stage. The PADP will participate in the development of the systems and concurrently develop necessary infrastructure and expertise for the production and product support for the users. This approach is expected to address the problems hitherto faced by the users in exploiting DRDO developed systems in the field, thereby overcoming time delays in crucial projects.The Rustom UAV program will again be a multi work center activity including the development of efficient lightweight airframes, advanced flight control systems including automatic take-off and landing systems, advanced data links, payloads such as imaging and eletronic support measure (ESM) systems. In contrast to the earlier approach of developing every conceivable technology, ADE plans to procure various payloads and sub-systems for the initial phase of development while simultaneously developing indigenous capability in the identified areas.The Rustom

UAV is being developed in two phases. In Phase I, an unmanned version of NAL's LCRA (Light Canard Research Aircraft), a Long-EZ design built in the 80s for research purposes, will be used as the Rustom-I. As it is a single engine system which does not have the endurance or payload that would meet the DRDO requirements, it is only used to develop technologies and subsystems. This technology initiative project is under progress, and a lot of subsystems are currently being qualified on the unmanned version of LCRA, which is basically a Rutan Long-EZ derivative. It was publicly displayed at Aerosem 2008, a celebration for the golden jubilee of DRDO at ADE in Bangalore, along with sub-scaled RC models of both Phase I and II articles. Low speed trials were done on Sept 22, high speed ones followed in October and flight testing followed suit.

Phase II concerns a totally different design, the Rustom-H, that owes nothing to Burt Rutan's design. It is a Medium-Altitude Long-Endurance Unmanned Aerial Vehicle (MALE UAV), a twin engine system designed to carry out surveillance and reconnaissance missions. It is being developed for all three services of Indian Armed Forces. DRDO and the services have been interacting extensively to arrive at a mutually acceptable qualitative requirement that would meet the long-term requirements of the services. Rustom is supposed to match the performance and requirements of similar international UAVs such as the Heron.The T-tail is because of the need to house ESM/CSM antennas on the tips of the T — one can see three vertical pieces on each tip, which are the CSM/ESM antennas — the need to perch them without interference having ruled out a Y-tail. The tail portion, both horizontal and vertical, does not contain any fuel because there is too much CG shift if the fuel is loaded there, therefore fuel is loaded only in the wing and the fuselage. The full tail is madeout of GFRP, so there is no reason to worry about the tail spoiling the RCS signature. Besides service ceiling is high enough to evade detection by ground based radars, and airborne radars are not a problem either because the body is fully made of composite materials.Rustom will be launched by the conventional method and not the launcher as in the case of the group's Lakshya and Nishant. Rustom will be able to see the enemy territory up to a distance of 250 km and carry a variety of cameras and radar for surveillance. Being a long endurance UAV, it will be very useful for both military and civil applications such as monitoring the enemy's order of battle, traffic monitoring, border patrols, disaster management and prevention of drug trafficking and infiltration, etc. Indian armed forces as well as coast guard and police forces require such a UAV in large numbers in order to meet their military and civil needs.

Phase II will proceed once the production agency and development partner (PADP) has been identified. The ADE officials indicated that the requests for proposals (RFP) would shortly be issued to four vendors which are the Tatas, Larsen and Toubro, Godrej and Hindustan Aeronautics Limited-Bharat Electronics (joint bid) who were chosen out of the 23 firms that responded. Currently, negotiations are underway between these companies and the three Indian armed forces since the private majors are looking for support and commitment from them before they start executing any development and production plans. This is because of the fact that the chosen PADP will also have a financial stake in the Rustom project. The Armed Forces would also be asked to take up a financial stake and the Indian government may have to guarantee that a specific number of Rustom UAVs will be bought. ADE will be the main agency taking up the project and the project coordinator. DRDO laboratories such as DEAL, Dehradun, LRDE, Bangalore and DLRL, Hyderabad will be the other work centers.The Rustom-H UAV has already been displayed in full-scale model form at Aero India '09. A 1:2 model of the Rustom has already completed control surface tests and low speed taxi trials, but it will be three years to the first flight of the real FSD article, however. The program is expected to culminate in a viable operational system by the end of 2012. As a side note, it is worthy of mention that the Rustom UAVs have been named after Rustom Behram Damania, a former professor of IISc, Bangalore who died in 2001 and who forming the starting point and nucleus of small aircraft design at National Aeronautical Laboratories (NAL) during the 1980s. Indeed, the Rustom-1's forerunner, the LCRA, was the first design built under his auspices.

Population: 1 prototype (serial unknown), not yet in production

RUSTOM-I

Endurance:12hours
Payload:75kg
Range:250km(estimated)
Fuel: located in wings and in place of cockpit

RUSTOM-H

Specifications:
Take-off/landing:conventional / ATOL
Service ceiling: 30,000 ft (9,144 m) (earlier source gave 35,000 ft.)
Endurance: > 24 hrs on station at 1000 km
Wingspan: 20 m (65.616 ft)
Empty weight: 1,800 kg (3968.32 lbs)
Maximum speed: 225 km/h (139.81 mph)
Engine performance: 128 Nm @ 5800 RPM

Operational range:

Direct line of sight: 250 km
With relay: 350 km

Payload:

Electro-optic payload : Day and night electro-optic sensors
Radar payloads: Synthetic Aperture Radar (SAR) / Maritime Patrol Radar (MPR)
ESM payloads: ELINT & COMINT
Payload capacity: 350 kg
Crew/passengers:unmanned

DESIGN

LCRA / Rutan Long-EZ Derivative

The full scale prototype is an unmanned version of NAL's LCRA (Light Canard Research Aircraft). ADE removed the pilot's seat and made the required electrical, mechanical and aerodynamic modifications. The LCRA was based on Rutan Long-EZ a homebuilt ac designed by Burt Rutan's Rutan Aircraft Factory. The aircraft is freely available in kit form. According to Wikipedia, it "is designed for fuel-efficient long-range flight, with a range of just over 2,000 miles (3,200 km). It can fly for over ten hours and up to 1,600 miles (2,600 km) on 52 gallons (200 liters) of fuel.Equipped with a rear-seat fuel tank, a Long-EZ has flown for 4,800 miles (7,700 kilometers)."

Design and development

With the Rustom MALE UAV project, DRDO intends to move away from traditional ways of developing products whereby laboratories under DRDO, like the Aeronautical Development Establishment (ADE), which is involved in this project, develop and finalise the product and transfer technology to a production agency.

DRDO will follow a practice of concurrent engineering where initial design efforts also take into consideration production issues, with the production agency participating in the development of the system right from the design stage. The agency will also follow up issues related to infrastructure and expertise for the product and its support, thereby overcoming time delays in crucial projects.[5]

Rustom which has a wingspan of 20 metres and weighs 1,800 kg, will be launched by the conventional method and not the launcher as in the case of the Lakshya. Rustom will be able to see the enemy territory up to a distance of 250 km and carry a variety of cameras and radar for surveillance.

Stealth technology

Stealth technology also termed LO technology (low observable technology) is a sub-discipline of military tactics and passive electronic countermeasures,[1] which cover a range of techniques used with personnel, aircraft, ships, submarines, and missiles, to make them less visible (ideally invisible) to radar, infrared,[2] sonar and other detection methods.Development in the United States occurred in 1958,[3][4] where earlier attempts in preventing radar tracking of its U-2 spy planes during theCold War by the Soviet Union had been unsuccessful.[5] Designers turned to develop a particular shape for planes that tended to reduce detection, by redirecting electromagnetic waves from radars.[6] Radar-absorbent material was also tested and made to reduce or block radar signals that reflect off from the surface of planes. Such changes to shape and surface composition form stealth technology as currently used on the Northrop Grumman B-2 Spirit "Stealth Bomber".[4] The concept of stealth is to operate or hide without giving enemy forces any indications as to the presence of friendly forces. This concept was first explored through camouflage by blending into the background visual clutter. As the potency of detection and interception technologies (radar,IRST, surface-to-air missiles etc.) have increased over time, so too has the extent to which the design and operation of military personnel and vehicles have been affected in response. Some military uniforms are treated with chemicals to reduce their infrared signature. A modern "stealth" vehicle will generally have been designed from the outset to have reduced or controlled signature. Varying degrees of stealth can be achieved. The exact level and nature of stealth embodied in a particular design is determined by the prediction of likely threat capabilities.

History

In England, irregular units of gamekeepers in the 17th century were the first to adopt drab colours (common in the 16th century Irish units) as a form of camouflage, following examples from the continent.Yehudi lights were successfully employed in World War II by RAFShorts Sunderland aircraft in attacks on U-boats. In 1945 a Grumman Avenger with Yehudi lights got within 3,000 yards (2,700 m) of a ship before being sighted. This ability was rendered obsolete by the radar of the time.The U-boat U-480 may have been the first stealth submarine. It featured a rubber coating, one layer of which contained circular air pockets to defeat ASDIC sonar.One of the earliest stealth aircraft seems to have been the Horten Ho 229 flying wing. It included carbon powder in the glue to absorb radio waves.[7] Some prototypes were built, but it was never used in action.In 1958, the CIA requested funding for a reconnaissance aircraft, to replace U-2 spy planes[8] in which Lockheed secured contractual rights to produce the aircraft.[3]"Kelly" Johnson and his team at Lockheed's Skunk Works were assigned to produce the A-12 or OXCART the first of the former top secret classified Blackbird series which operated at high altitude of 70,000 to 80,000 ft and speed of Mach 3.2 to avoid radar detection. Radar absorbent material had already been introduced on U-2 spy planes, and various plane shapes had been developed in earlier prototypes named A1 to A11 to reduce its detection from radar.[4] Later in 1964, using prior models, an optimal plane shape taking into account compactness was developed where another "Blackbird", the SR-71, was produced, surpassing prior models in both altitude of 90,000 ft and speed of Mach 3.3.[4]During 1970s, the U.S. Department of Defence then launched a project called Have Blue to develop a stealth fighter. Bidding between both Lockheed and Northrop for the tender was fierce to secure the multi-billion dollar contract. Lockheed incorporated in its program paper written by a Soviet/Russian physicist Pyotr Ufimtsev in 1962 titled Method of Edge Waves in the Physical Theory of Diffraction, Soviet Radio, Moscow, 1962. In 1971 this book was translated into English with the same title by U.S. Air Force, Foreign Technology Division (National Air Intelligence Center), Wright-Patterson AFB, OH, 1971. Technical Report AD 733203, Defense Technical Information Center of USA, Cameron Station, Alexandria, VA, 22304-6145, USA. This theory played a critical role in the design of American stealth-aircraft F-117 and B-2.[9][10][11] The paper was able to find whether a plane's shape design would minimise its detection by radar or its radar cross-section (RCS) using a series of equations[12] could be used to evaluate the radar cross section of any shape. Lockheed used it to design a shape they called the Hopeless Diamond, securing contractual rights to mass produce the F-117 Nighthawk.The F-117 project began with a model called "The Hopeless Diamond" (a wordplay on the Hope Diamond) in 1975 due to its bizarre appearance. In 1977 Lockheed produced two 60% scale models under the Have Blue contract. The Have Blue program was a stealth technology demonstrator that lasted from 1976 to 1979. The success of Have Blue lead the Air Force to create the Senior Trend[13][14] program which developed the F-117.

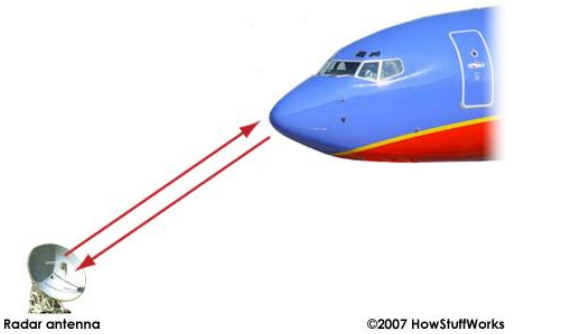
How does stealth technology work

The article How Radar Works talks about the basic principles of a radar system. The idea is for the radar antenna to send out a burst of radio energy, which is then reflected back by any object it happens to encounter. The radar antenna measures the time it takes for the reflection to arrive, and with that information can tell how far away the object is. The metal body of an airplane is very good at reflecting radar signals, and this makes it easy to find and track airplanes with radar equipment.

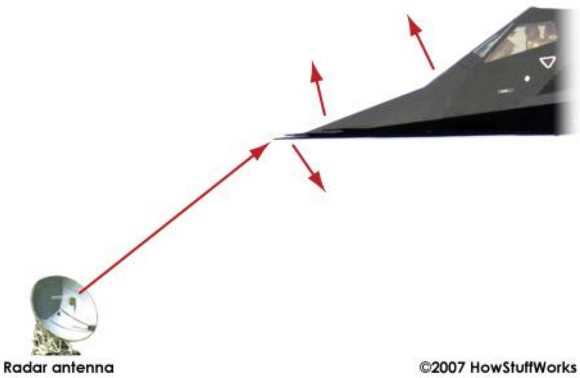
The goal of stealth technology is to make an airplane invisible to radar. There are two different ways to create invisibility:

- The airplane can be shaped so that any radar signals it reflects are reflected away from the radar equipment.
- The airplane can be covered in materials that absorb radar signals.

Most conventional aircraft have a rounded shape. This shape makes them aerodynamic, but it also creates a very efficient radar reflector. The round shape means that no matter where the radar signal hits the plane, some of the signal gets reflected back:



A stealth aircraft, on the other hand, is made up of completely flat surfaces and very sharp edges. When a radar signal hits a stealth plane, the signal reflects away at an angle, like this:



In addition, surfaces on a stealth aircraft can be treated so they absorb radar energy as well. The overall result is that a stealth aircraft like an F-117A can have the radar signature of a small bird rather than an airplane. The only exception is when the plane banks -- there will often be a moment when one of the panels of the plane will perfectly reflect a burst of radar energy back to the antenna.

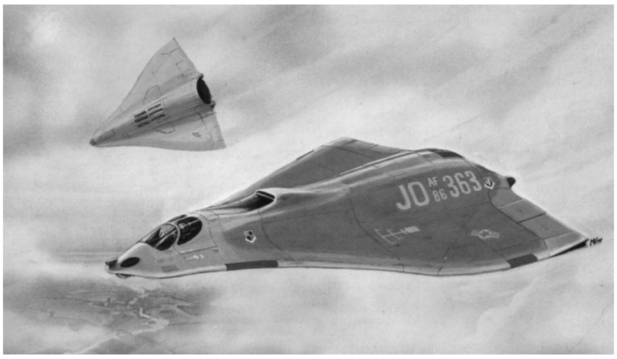
Basic Principles of Modern Stealth Technology

Military stealth technology — such as is used, for example, in the B-2 bomber, the F-117 fighter-bomber and the F-22 fighter, and as is intended for the future Comanche helicopter, and the next-generation tank which is intended to replace the current M1A2 Abrams tank — is based on the principle that the stealthy craft remains invisible to detecting radar and infrared sensors, especially at long ranges.

With respect to radar, this is accomplished, in basic principle, by the stealthy craft absorbing almost all the radar waves emanated by detecting radar sources, and/or reflecting or deflecting the detecting radar in direction(s) other than towards the detecting sensors. With respect to infrared, the objective of stealth is achieved, in basic principle, by the stealthy craft minimising heat from its engines and other heat-emitting spots.

As a result of applying the above principles, detecting sensors searching for a stealthy craft cannot detect any radar or infrared signal emanating from the craft, except perhaps at very closedistances, when it may already be too late to do anything about it from a military viewpoint. The craft, therefore, cannot be observed by radar or infrared sensors. Advance Concepts

STEALTH TECHNOLOGY



Artist's rendering of what the CSIRS stealth fighter may look like. This aircraft would penetrate Soviet (or other) air defence systems, to carry out reconnaissance or precision strike missions over heavily defended, high value targets. The aircraft would employ carbon composite structure, FLIR/TV passive sensors and an advanced passive detection system, to monitor hostile emissions. Weapons and fuel are carried internally (Illustration by Mark Kopp).The aerial battlefield of the 1990s is liable to be a very hostile environment. The USSR is currently completing the develop ment of a whole new generation of air combat aircraft and AAMs, aircraft designed to match or exceed the performance of the teen-series fighters, equipped with long range look down-shootdown radar and configured to operate in conjunction with AWACS/AEW class aircraft. The current MiG-25M Foxhound Foxbat derivative and the new Sukhoi Su-27 Ram-K, apparently a derivative of the F-111 Tornado class Fencer, both appear to be equipped with a Soviet development of the Hughes AWG-9 radar/fire control, a valuable gift from Khomeini's regime. One may, in fact, reasonably assume that the AWG-9 was copied down to the last transistor, in the same fashion as the Tupolev and Shvetsov bureaux duplicated the state-of-the-art B-29, in 1946. If we set aside the air-superiority role, where the Russians are preparing the MiG-29 Ram-L, a Mach 2.5 twin-engine, twin-fin air combat fighter with a reported thrust to weight ratio of 1.4:1, and focus on penetrating Soviet air-defences, be it battlefield or homeland, Western aircraft will have to penetrate not only swarms of lookdown-shootdown fighters, but also SAM belts, supported by massive phased array radars, and presumably also AAA point defence systems. As one may observe, a rather nasty lot to contend with, as a whole.

Infra-red Signature

Infra-red radiation is emitted by all heat sources in the aircraft, whatever they may be. The IR band as a whole comprises all electromagnetic radiation with wavelengths between 800 um and 1000 um, though the region of interest here is the near infrared, i.e. shorter than 10 um. That is because the predominant wavelengths emitted by bodies at temperatures of the order of hundreds of degrees fall into this band. The principal source of IR in any powered aircraft is the propulsion. Jet engines being heat engines with less than 100 per cent efficiency, they radiate waste energy as heat, in two basic ways. The tailpipe of the jet engine is a very intense source of IR energy, the intensity and wavelengths depending very much on the type of engine. Turbojets have EGTs (exhaust gas temperature) of the order of 1000�C, though newer turbo fans have turbine EGTs around 1350�C. This leads to emissions in the 1 to 2.5 um band. The second major source of IR is the exhaust gas plume, formed as the exhaust gases flow out of the tailpipe and expand. The plume, on dry thrust, is cooler than the tailpipe, particularly with turbofans, which mix cool bypass air with the turbine exhaust gases. These emissions cover most of the near IR band. Lighting the afterburner will dramatically increase the temperature of the plume, it will then dominate the aircraft's signature. Further IR is emitted by hot parts of the engine, particularly the afterburner nozzle.

Electromagnetic Emissions

Modern combat aircraft emit electromagnetic waves over a very wide spectrum. The greatest source is the radar, whether operating in air-air or air-ground modes, emitting pulses of power up to the order of hundreds of kilowatts. Given that an opponent has a warning receiver equally as sensitive as the radar's own receiver, he will detect the radar at least a4 twice the distance necessary for the radar to pick up a return. This means that a radar equipped aircraft does an excellent job advertising both its position and identity, as a spectral analyser of one or another sort, coupled with a computer memory file, will identify the radar quite readily. The obvious solution to this problem is flying with one's radar set shut down, which, of course, creates another set of problems, related to the detection of the enemy. Another source of emissions is the use of radar/radio altimeters and Doppler navigation systems, all of which rely on the transmission of beams from the aircraft to the Earth's surface, in order to make measurements. The solution would appear to be the use of inertial navigation and perhaps lasers or millimetric wave systems for height measurement, as these allow much narrower beams.

Radar Signature

The radar signature of an aircraft is a measure of its detectability by a particular radar system. Electromagnetic waves, as emitted by radar, for instance, propagate through space only until confronted with a different medium. Depending on the particular medium, part of the energy will be reflected back to the source, part will penetrate into the surface. Given that the medium is conductive (e.g. a metal aircraft skin) and the waves are at microwave (typically radar) frequencies, most of the energy will be reflected. However, if the medium has electrical properties close to that of free space, as far as the wave is concerned, there will be little if any reflection and the impinging wave will penetrate, propagating through the material. This may imply the simple solution of building an aircraft of such material, however, internal systems, e.g. engine, would then reflect. Fortunately, these materials can be made lossy (absorbing the energy and re-emitting it as heat) and then a physical phenomenon known as the skin-effect occurs; this confines the electrical and magnetic fields (voltages and currents), generated by the impinging wave, to a thin surface layer, given by the so called skin depth, characteristic of a material at a given frequency.

Northrop Advanced Technology Bomber.

The ATB, or Stealth Bomber, is to become the airborne element of the US nuclear strike triad, it will replace the B-1B in the penetration role and carry out long range nuclear strike missions. Northrop is leading the project, presumably for their great experience with both ECM and large flying wing aircraft, Boeing and Vought are co-operating. Total contracts for development are worth $7300 million. The ATB is a heavily classified project, in fact so classified, that nobody really knows anything specific, at this stage. It is assumed the aircraft will be a delta platform flying wing, as this configuration offers both a low radar cross-section and a good lift to drag ratio, allowing for efficient high speed cruise. Initial estimates of the powerplants to be used suggested four high bypass ratio turbofans, chosen for fuel economy and low IR signature. Current estimates favour two variable cycle engines (a variable cycle engine allows for continuous changes of bypass ratio to meet either thrust or fuel consumption require ments, behaving much like a high bypass turbofan at one extreme or a turbojet at the other), the suggested size has also decreased. No specific estimates of crew size seem to be available, though one could assume two to four men. Engine inlets and exhausts would presumably lie on the upper surface of the aircraft, employing inlet S-bends, exhaust baffles and most likely, fairly long inlet and exhaust ducts. Airframe and skin structures would be carbonfibre composite. Weapons would be carried in an internal weapons bay, most likely free fall nuclear bombs, as the small size would preclude the carriage of stand-off missiles or cruise missiles. One could assume a mission profile of the following sort - takeoff with full internal fuel from the continental US or other safe airbases, followed by a very steep climb, on full thrust, to a cruising altitude, likely above 40,000 feet. Once at cruise altitude, the engines would switch to a high bypass mode and the aircraft would begin a high subsonic, or low supersonic cruise to the target area. Longer missions may require in-flight refuelling. Navigation would employ inertial and satellite systems, though some form of TERCOM update could be used, over safe zones. Hostile airspace would be penetrated at medium to high altitudes, exploiting cloud cover wherever possible to confuse IR surveillance systems. An ATB would carry a comprehensive passive ECM system, which could classify and locate all hostile sources of radiation. This data would be passed on to a graphic image generating computer, which would synthesise a picture of the landscape, with lethal zones (volumes of space around SAM/radar/AEW systems) clearly displayed. The pilot would then steer the aircraft between these zones, avoiding detection and/or tracking, simply by following his TV screen or HUD. Targets would be attacked with free fall weapons, though these may be equipped with inertial or TV (smart image recognising systems) terminal guidance, which would also allow stand-off ranges of several miles, useful for nuclear strike. Stealth technology is in its beginnings, at this stage it isn't even apparent whether the concept will prove itself in operation or become a multimillion dollar flop, though it is fair to assume that whatever the outcome, a lot will be learnt about the reduction of signatures and a lot of that will be incorporated in other projects. It is, in its essence, a massive exercise at seeing without being seen and it does involve a lot of new technology, which must be integrated very thoroughly.

Only time will tell how successful the concept actually is.

GLOSSARY OF TERMS

ENDURANCE

In aviation, Endurance is the maximum length of time that an aircraft can spend in cruising flight. Endurance is sometimes erroneously equated with range. The two concepts are distinctly different: range is a measure ofdistance flown while endurance is a measure of time spent in the air. For example, a typical sailplane exhibits high endurance characteristics but poor range characteristics.

Endurance can be written as:

$$E = \int_{t_1}^{t_2} dt = -\int_{W_1}^{W_2} \frac{dW}{F} = \int_{W_2}^{W_1} \frac{dW}{F}$$

where W stands for fuel weight, F for fuel flow, t for time.

Endurance can factor into aviation design in a number of ways. Some aircraft, such as the P-3 Orion or U-2spyplane, require high endurance characteristics as part of their mission profile (often referred to as loiter time (on target)). Endurance, like range, is also related to fuel efficiency; fuel efficient aircraft will tend to exhibit good endurance characteristics.

RANGE

The maximal total range is the distance an aircraft can fly between takeoff and landing, as limited by fuel capacity in powered aircraft, or cross-country speed and environmental conditions in unpowered aircraft.

Ferry range means the maximum range the aircraft can fly. This usually means maximum fuel load, optionally with extra fuel tanks and minimum equipment. It refers to transport of aircraft for use on remote location.

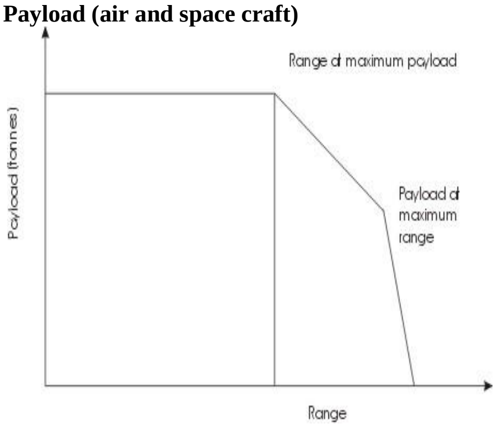
Combat range is the maximum range the aircraft can fly when carrying ordnance.

Combat radius is a related measure based on the maximum distance a warplane can travel from its base of operations, accomplish some objective, and return to its original airfield with minimal reserves.

The fuel time limit for powered aircraft is fixed by the fuel load and rate of consumption. When all fuel is consumed, the engines stop and the aircraft will lose its propulsion. For unpowered aircraft, the maximum flight time is variable, limited by available daylight hours, weather conditions, and pilot endurance.

The range can be seen as the cross-country ground speed multiplied by the maximum time in the air. The range equation will be derived in this article for propeller and jet aircraft.

Payload (air and space craft)



In military aircraft or space exploration, the payload is the carrying capacity of an aircraft or space ship, including cargo,munitions, scientific instruments or experiments. External fuel, when optionally carried, is also considered part of the payload.

The fraction of payload to the total liftoff weight of the air or spacecraft is known as the "payload fraction". When the weight of the payload and fuel are considered together, it is known as the "useful load fraction". In spacecraft, "mass fraction" is normally used, which is the ratio of payload to everything else, including the rocket structure.[1]

There is a natural trade-off between the payload and the range of an aircraft. A payload range diagram (also known as the "elbow chart") illustrates the trade-off.

The top horizontal line represents the maximum payload. It is limited structurally by maximum zero fuel weight(MZFW) of the aircraft. Maximum payload is the difference between maximum take off weight and maximum fuel weight (OEW). Moving left-to-right along the line shows the constant maximum payload as the range increases. More fuel needs to be added for more range.

Weight in the fuel tanks in the wings does not contribute as significantly to the bending moment in the wing as does weight in the fuselage. So even when the airplane has been loaded with its maximum payload that the wings can support, it can still carry a significant amount of fuel.

The vertical line represents the range at which the combined weight of the aircraft, maximum payload and needed fuel reaches the maximum take-off weight (MTOW) of the aircraft. If the range is increased beyond that point, payload has to be sacrificed for fuel.

The maximum take-off weight is limited by a combination of the maximum net power of the engines and the lift/drag ratio of the wings. The diagonal line after the range-at-maximum-payload point shows how reducing the payload allows increasing the fuel (and range) when taking off with the maximum take-off weight.

The second kink in the curve represents the point at which the maximum fuel capacity is reached. Flying further than that point means that the payload has to be reduced further, for an even lesser increase in range. The absolute range is thus the range at which an aircraft can fly with maximum possible fuel without carrying any payload.

RUSTOM-H

Rustom-1 which has completed all test flights is likely to be used as a short-range UAV by the users.Sources tell Tarmak007 that Rustom-1 (2006-2011) was a technology interface (TI) project for Rustom-H and it has completed all test flights.

Among the proven capabilities include: (i) taxi take-off with automatic nose-wheel steering; (ii) extended pilot control for taking the platform to the centre of the runway; (iii) autopilot mode for the flights, including way-point navigation (WPN) and get-you-home features; (iv) redundant Flight Control System, hardware and software and (v) integrated C-Band data-link.

“These proven features have made Rustom-1 a UAV of its own, which the users (Army) are interestedto use as a short-range platform,” sources said.

With the Rs 1,500 crore already sanctioned in February 2011 for the Rustom-H project, the DRDO now hopes to have the platform flying latest by 2014 March. “We are confident that the user will fly it as a high-altitude long endurance (HALE) platform,” sources said.

Interestingly, the Rustom-H project will be henceforth called as Rustom-II. This forced name-change was the result of a ‘possible typing error’ by some MoD staff during the fund sanction phase, early this year. “The sanction came as Rustom-II and we realised what could have gone wrong. Anyways, the first one was called Rustom-I and it suits well to call the next one Rustom-II -- instead of Rustom-H. Just a small name-change and the features will remain the same as envisaged for Rustom-H," sources said. What's in a name, after all? Tarmak007 -- A bold blog on Indian defence: Rustom-1 to don the role of short-range UAV; Rustom-H project is officially R-II now.

MY DESIGN CONSIDERATIONS
HISTORY

Tilt rotor:

- A tilt rotor is an aircraft which generates lift and propulsion by way of one or more powered rotors (sometimes called prop rotors) mounted on rotating engine pods or nacelles usually at the ends of a fixed wing or an engine mounted in the fuselage with drive shafts transferring power to rotor assemblies mounted on the wingtips. It combines the vertical lift capability of a helicopter with the speed and range of a conventional fixed-wing aircraft. For vertical flight, the rotors are angled so the plane of rotation is horizontal, lifting the way a helicopter rotor does. As the aircraft gains speed, the rotors are progressively tilted forward, with the plane of rotation eventually becoming vertical. In this mode the wing provides the lift, and the rotor provides thrust as a propeller. Since the rotors can be configured to be more efficient for propulsion (e.g. with root-tip twist) and it avoids a helicopter's issues of retreating blade stall, the tilt rotor can achieve higher speeds than helicopters.
- A tilt rotor aircraft differs from a tilt wing in that only the rotor pivots rather than the entire wing. This method trades off efficiency in vertical flight for efficiency in STOL/STOVL operations.

Fig 1.1: The Bell-Boeing V-22 Osprey

- The idea of constructing Vertical Take-Off and Landing aircraft using helicopter-like rotors at the wingtips originated in the 1930s. The first design resembling modern tilt rotors was patented by George Lehberger in May 1930, but he did not further develop the concept. In World War II, a German prototype, called the Focke-Achgelis FA-269, was developed starting in 1942, but never flew.

- Two prototypes which made it to flight were the one-seat Transcendental Model 1-G and two seat Transcendental Model 2, both powered by single reciprocating engines. Development started on the Model 1-G in 1947, though it did not fly until 1954. The Model 1-G flew for about a year until a crash in Chesapeake Bay on July 20, 1955, destroying the prototype aircraft but not seriously injuring the pilot. The Model 2 was developed and flew shortly afterwards, but the US Air Force withdrew funding in favor of the Bell XV-3 and it did not fly much beyond hover tests. The Transcendental 1-G is the first tilt rotor aircraft to have flown and accomplished most of a helicopter to aircraft transition in flight (to within 10 degrees of true horizontal aircraft flight).

- Built in 1953, the experimental Bell XV-3 flew until 1966, proving the fundamental soundness of the tilt rotor concept and gathering data about technical improvements needed for future designs.

Fig 1.2: A Bell XV-15 prepares to land

- VTOL DiscLoad-LiftEfficiency.PNG

A related technology development is the tilt wing. Although two designs, the Canadair CL-84 Dynavert and the LTV XC-142, were technical successes, neither entered production due to other issues. Tilt rotors generally have better hover efficiency than tilt wings, but less than helicopters.

- In 1968, Westland Aircraft displayed their own designs—a small experimental craft (We 01C) and a 68-seater transport We 028—at the SBAC Farnborough Air show.[5]

- In 1972, with funding from NASA and the U.S. Army, Bell Helicopter Textron started development of the XV-15, a twin-engine tilt rotor research aircraft. Two aircraft were built to prove the tilt rotor design and explore the operational flight envelope for military and civil applications.[6][7]

- In 1981, using experience gained from the XV-3 and XV-15, Bell and Boeing Helicopters began developing the V-22 Osprey, a twin-turbo shaft military tilt rotor aircraft for the U.S. Air Force and the U.S. Marine Corps.[6]

- Bell teamed with Boeing in developing a commercial tilt rotor, but Boeing went out in 1998 and Augusta came in for the Bell/Augusta BA609.[7][8] This aircraft was re-designated as the AW609 following the transfer of full ownership to Augusta Westland in 2011.[9] Bell has also developed a tilt rotor unmanned aerial vehicle (UAV), the TR918 Eagle Eye.

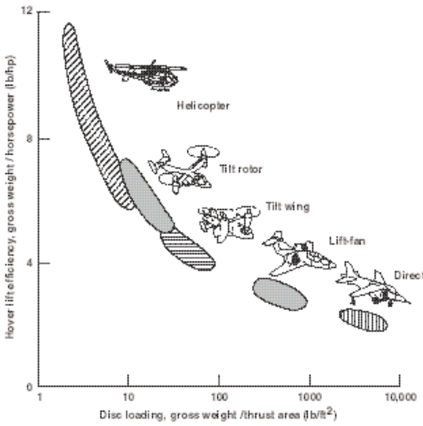


Fig 1.3: Graph between hover lift efficiency, gross weight/horsepower vs
Disc loading, gross weight/thrust area

- Around 2005[10]-2010,[11] Bell and Boeing teamed up again to perform a conceptual study of a larger Quad Tilt Rotor (QTR) for the US Army's Joint Heavy Lift (JHL) program. The QTR is a larger, four rotor versions of the V-22 with two tandem wings sets of fixed wings and four tilting rotors.

- In January 2013, the FAA defined US tilt rotor noise rules to comply with ICAO rules. A noise certification will cost $588,000, same as for a large helicopter.[12][13]

- Augusta Westland says they have free-flown a manned electric tilt rotor in 2013, with its rotors inside the wingspan.
- In 2013, Bell Helicopter CEO John Garrison responded to Boeing's taking a different airframe partner for the US Army's future lift requirements by indicating that Bell would take the lead itself in developing the Bell V-280 Valor,[16] with Lockheed Martin.

- In 2014, the Clean Sky 2 program (by the European Union and industry) awarded Augusta Westland and its partners $328 million to develop a "next-generation civil tilt rotor" design for the offshore market, with Critical Design Review near the end of 2016. The goals are tilting wing sections, 11 tones Maximum takeoff weight, seating for 19 to 22 passengers, a ceiling of 25,000 feet, a range of 500 nautical miles and a top speed of 330 knots.

Technical considerations:

Controls:

- In vertical flight, the tilt rotor uses controls very similar to a twin or tandem-rotor helicopter. Yaw is controlled by tilting its rotors in opposite directions. Roll is provided through differential power or thrust. Pitch is provided through rotor cyclic or nacelle tilt. Vertical motion is controlled with conventional rotor blade pitch and either a conventional helicopter collective control lever (as in the Bell/Augusta BA609) or a unique control similar to a fixed-wing engine control called a thrust control lever (TCL) (as in the Bell-Boeing V-22 Osprey).

Speed and payload issues:

- The tilt rotor's advantage is significantly greater speed than a helicopter. In a helicopter the maximum forward speed is defined by the turn speed of the rotor; at some point the helicopter will be moving forward at the same speed as the spinning of the backwards-moving side of the rotor, so that side of the rotor sees zero or negative airspeed, and begins to stall. This limits modern helicopters to cruise speeds of about 150 knots / 277 km/h. However, with the tilt rotor this problem is avoided, because the prop rotors are perpendicular to the motion in the high-speed portions of the flight regime (and thus never suffering this reverse flow condition), meaning that the tilt rotor has relatively high maximum speed—over 300 knots / 560 km/h has been demonstrated in the two types of tilt rotors flown so far, and cruise speeds of 250 knots / 460 km/h are achieved.

- This speed is achieved somewhat at the expense of payload. As a result of this reduced payload, some estimate that a tilt rotor does not exceed the transport efficiency (speed times payload) of a helicopter, while others conclude the opposite. Additionally, the tilt rotor propulsion system is more complex than a conventional helicopter due to the large, articulated nacelles and the added wing; however, the improved cruise efficiency and speed improvement over helicopters is significant in certain uses. Speed and, more importantly, the benefit to overall response time is the principal virtue sought by the military forces that are using the tilt rotor. Tilt rotors are inherently less noisy in forward flight (airplane mode) than helicopters.[citation needed] This, combined with their increased speed, is expected to improve their utility in populated areas for commercial uses and reduce the threat of detection for military uses. Tilt rotors, however, are typically as loud as equally sized helicopters in hovering flight. Noise simulations for a 90-passenger tilt rotor indicate lower cruise noise inside the cabin than a Bombardier Dash 8 airplane, although low-frequency vibrations may be higher.

- Tilt rotors also provide substantially greater cruise altitude capability than helicopters. Tilt rotors can easily reach 6,000 m / 20,000 ft or more whereas helicopters typically do not exceed 3,000 m / 10,000 ft altitude. This feature will mean that some uses that have been commonly considered only for fixed-wing aircraft can now be supported with tilt rotors without need of a runway. A drawback however is that a tilt rotor suffers considerably reduced payload when taking off from high altitude.

Mono tilt rotor:

- A mono tilt rotor aircraft uses a tiltable rotating propeller, or coaxial proprotor, for lift and propulsion. For vertical flight the proprotor is angled to direct its thrust downwards, providing lift. In this mode of operation the craft is essentially identical to a helicopter. As the craft gains speed, the coaxial proprotor is slowly tilted forward, with the blades eventually becoming perpendicular to the ground. In this mode the wing provides the lift, and the wing's greater efficiency helps the tiltrotor achieve its high speed. In this mode, the craft is essentially a turboprop aircraft.

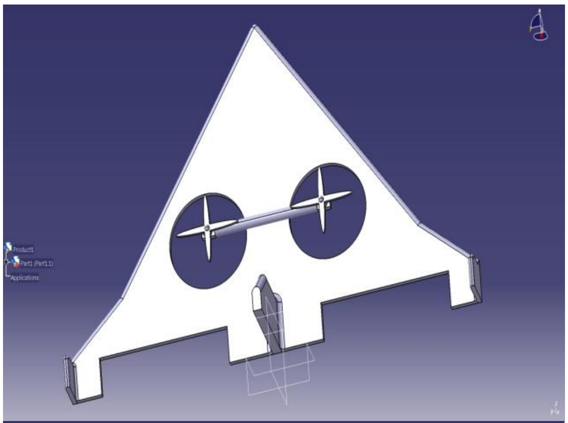
- A mono tiltrotor aircraft is different from a conventional tiltrotor in which the proprotors are mounted to the wing tips, in that the coaxial proprotor is mounted to the aircraft's fuselage. As a result of this structural efficiency, a mono tiltrotor exceeds the transport efficiency (speed times payload) of both a helicopter and a conventional tiltrotor. One design study concluded that if the mono tiltrotor could be technically realized, it would be half the size, one-third the weight, and nearly twice as fast as a helicopter.

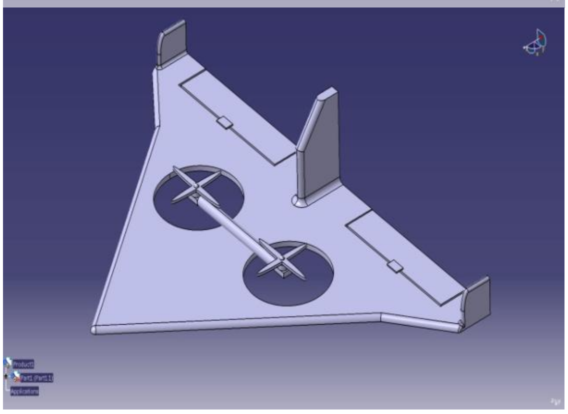
- In vertical flight, the mono tiltrotor uses controls very similar to a coaxial helicopter, such as the Kamov Ka-50. Yaw is controlled for instance by increasing the lift on the upper proprotor while decreasing the lift on the lower proprotor. Roll and pitch are provided through rotor cyclic. Vertical motion is controlled with conventional rotor blade blade pitch.

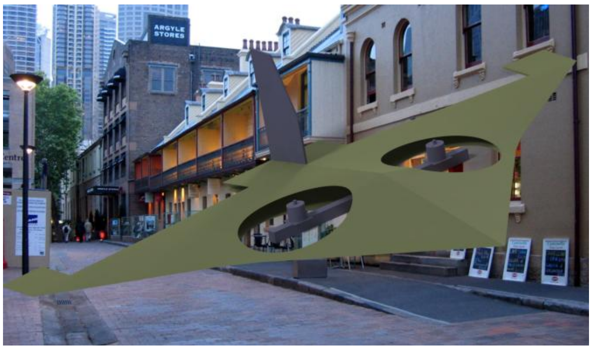
List of tilt rotor aircraft:

Fig : Curtiss-Wright X-19 experimental VTOL plane in flight

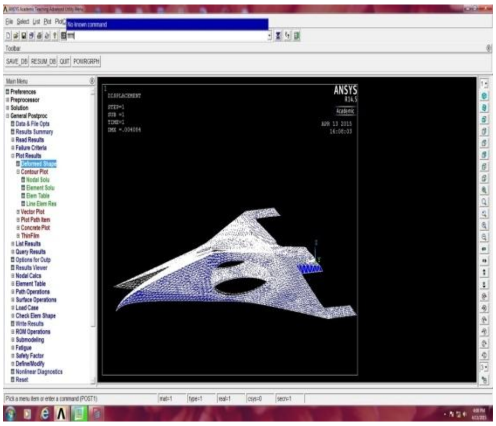
i. A BA609 (now AW609) in airplane mode at Paris Air Show 2007
ii. AgustaWestland AW609
iii. AgustaWestland Project Zero
iv. American Dynamics AD-150
v. Bell XV-3
vi. Bell XV-15
vii. Bell Eagle Eye
viii. Bell-Boeing V-22 Osprey
ix. Curtiss-Wright X-19
x. Focke-Achgelis Fa 269

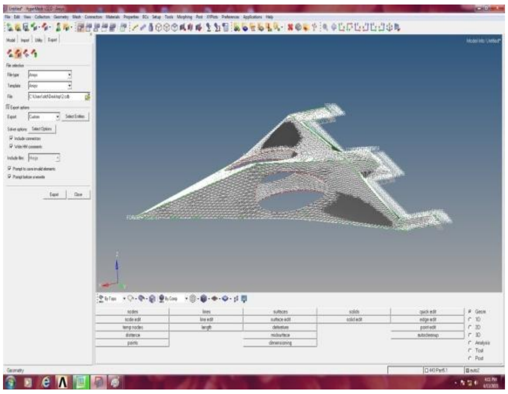


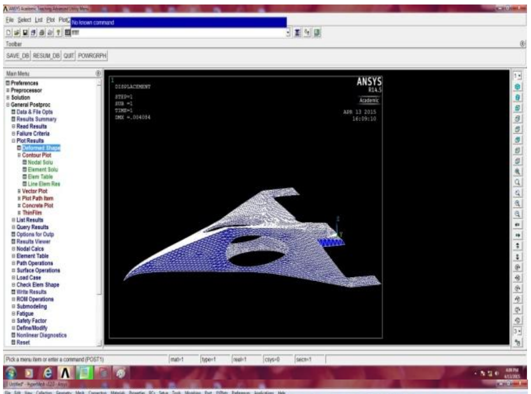


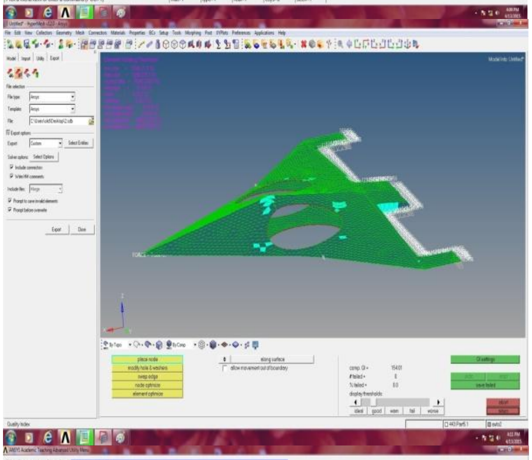


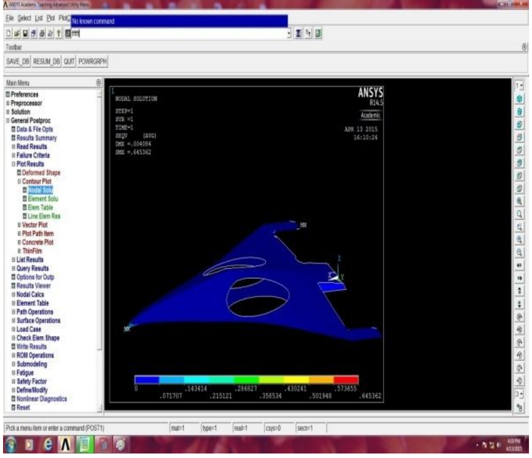
- This is a deltawing with tiltrotor design it is usefull for military operations and transportation purpose as well as it take VTOL (vertical take off and landing),we will do structural analysis onthismodel.











We perform to analysis of the model, meshing and stiffness of the model,and we also applying the loads on the prototype to analyse the von-mises stresses and displacements.

ADVANTAGES:

- The tilt rotor’s advantage is significantly greater speed than a helicopter.
- In a helicopter the maximum forward speed is defined by the turn speed of the rotor; at some point the helicopter will be moving forward at the same speed as the spinning of the backwards moving side of the rotor, so that side of the rotor sees zero or negative airspeed, and begins to stall
- This limits modern helicopters to cruise speeds of about 150 knots / 277 km/h.
- The tiltrotor this problem is avoided, be- cause the proprotors are perpendicular to the motion in the high speed portions of the flight regime (and thus never suffering this reverse flow condition), meaning that the tiltrotor has relatively high maximum speed over 300 knots / 560 km/h has been demonstrated in the two types of tiltrotors flown so far, and cruise speeds of 250 knots / 460 km/h are achieved.
- Tiltrotors are inherently less noisy in forward flight (airplane mode) than helicopters.
- The benefit to overall response time is the principal virtue sought by the military forces that are using the tiltrotor.
- Tiltrotors, however, are typically as loud as equally sized helicopters in hovering flight. Noise simulations for a 90-passenger tiltrotor indicate lower cruise noise inside the cabin than a Bombardier Dash 8 airplane, although low-frequency vibrations may be higher.

USING SOFTWARES:

- CATIAV5,
- ANSYS
- HYPERMES

Conclusion : By perform the analysis of the model, meshing and stiffness of the model,and we also applying the loads on the prototype to analyse the von-mises stresses and displacements.Tiltrotors, however, are typically as loud as equally sized helicopters in hovering flight. Noise simulations for a 90-passenger tiltrotor indicate lower cruise noise inside the cabin than a Bombardier Dash 8 airplane, although low-frequency vibrations may be higher.

REFERRENCES

[1] **range and endurance**:G.J.J. Ruigrok, Elements of airplane performance, Delft University Press
[2] **future of rustom-h**: http://www.indiandefence.com/forums/f7/rustom-1-don-role-short-range-uav%3B-rustom-h-project-officially-r-ii-now-9074/
[3] "Next Generation Civil Tiltrotor" AgustaWestland Springmann, Enno; Gottfried Hilscher (1997). *Focke: Flugzeuge und Hubschrauber von Heinrich Focke 1912-1961*. Aviatic-Verlag GmbH.ISBN 3-925505-36-9