Technology Focus

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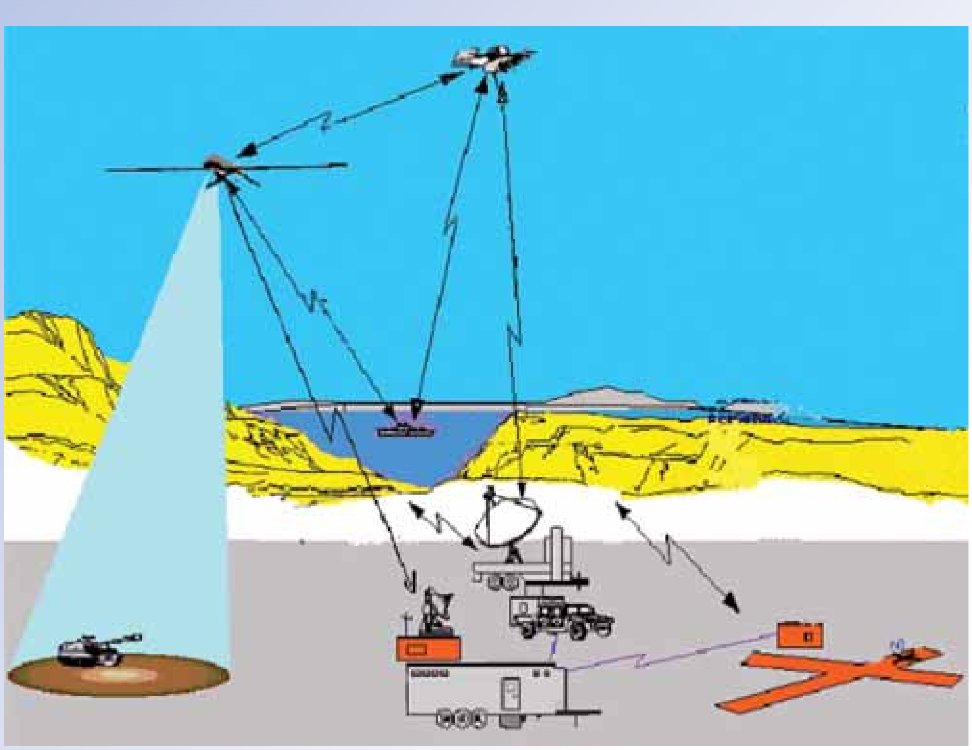
Unmanned Aircraft Systems and Technologies

Aeronautical Development Establishment, as a nodal agency of Defence Research and Development Organisation, has successfully designed and developed versatile Unmanned Aircraft Systems that have been inducted into the Indian Armed Forces.



Unmanned aerial vehicle: Operational scenario.

Unmanned Air Vehicles (UAVs) play a predominant role in the modern day warfare where emphasis is on surveillance, intelligence-gathering and dissemination of information. Within a few decades, these systems have evolved from performing a single role/mission to performing multiple missions like surveillance, monitoring, acquiring, tracking and destruction of target with the use of advanced technologies. UAVs serve as unique tools, which broaden battlefield situational awareness and the ability to see, target, and destroy the enemy by providing actionable intelligence to the lowest tactical levels.

A distinct advantage of UAVs is their cost-effectiveness. They can be developed, produced, and operated at lower costs compared to the cost of manned aircraft. The relative savings in engines, airframes, fuel consumption, pilot training, logistics, and maintenance are enormous.

The biggest advantage of UAVs, however, is that there is no risk to human lives. Unmanned platforms are the emerging lethal and non-lethal weapons of choice and have transformed the way the armed forces now prosecute operations. The probability of losing reconnaissance platforms to enemy fire is quite higher, thus making UAV a better option.

UAVs can be classified according to their roles as:

- Aerial targets: Used for weapon system evaluation and gunnery practice.
- Unmanned Combat Aerial Vehicle (UCAV): Carries weapon systems.
- Surveillance/Reconnaissance UAVs: For data collection and patrolling/spying.

Defence Research and Development Organisation (DRDO), has successfully designed and developed many versatile UAV systems that have been inducted into the Indian Armed Forces. Aeronautical Development Establishment (ADE), Bengaluru—the major aeronautical systems research laboratory of the DRDO involved in practically all major aspect of aeronautical research, design, and development relevant to military aviation—is in the forefront, as the nodal agency, in the development of UAVs for the Sevices.

This issue of *Technology Focus* covers some of the systems, which have been already developed and some of which are under advanced state of development.

COMPLETED PROJECTS

Mini Remotely Piloted Vehicle, Kapothaka

Kapothaka is a mini remotely piloted vehicle (RPV) demonstrator with an all-up-weight (AUW) of 130 kg and an endurance of 90 min. This RPV is equipped with TV and panoramic cameras.

Ulka

Ulka is an air-launched target with the following specifications:

Launch weight	:	360 kg
Power plant	:	Solid booster
Speed	:	Mach 0.7 to 1.1
Range	:	70 km (max.)
Altitude	:	100 m to 9 km
Endurance	:	5 min (max.)

Nishant

Nishant tactical UAV system for surveillance was conceived with mobility as an important requirement. It is launched using a hydro pneumatic launcher and recovered with an aero conical parachute and an impact attenuation system. High degree of automation built into the system reduces piloting skill requirements to a minimum during critical phases of launch and recovery. Nishant carries stabilised payload for both day and night missions. An onboard flight control and navigation system makes Nishant fly in autonomous waypoint navigation mode. Nishant can be used for day/night reconnaissance, target tracking and extraction of target coordinates, artillery fire correction, and damage assessment.

The rotary Wankel engine of

Kapothaka—mini remotely piloted vehicle.

Ulka—air launched target.

Nishant on launcher and in flight (inset).

Salient Features: Nishant

Flight endurance	:	4 ½ h
Altitude	:	3600 m AMSL
Speed cruise	:	125-150 kmph
Command range	:	175 km (160 km)
Payload data link	:	175 km (100 km)
Launch	:	Mobile hydro pneumatic
Recovery	:	Parachute/Landing bags
AUW	:	370 kg

Nishant has been indigenised in collaboration with National Aerospace Laboratories (NAL), Bengaluru, and Vehicle Research and Development Establishment (VRDE), Ahmednagar. The other upgrades of Nishant include altitude enhancement to 5.5 km and increase in endurance using electronic fuel injection (EFI) engine.

A wheeled version of Nishant, use of colour video, and integration of synthetic aperture radar (SAR) are other developments in progress. Indian Army has placed an order for four Nishant air vehicles and ground systems after successful user evaluation trials.

Lakshya

Pilotless target aircraft (PTA) Lakshya is the result of ADE's development plan and successfully meets the requirements of the Indian Defence Forces. The main feature of Lakshya is the tow target system that makes it cost-effective and versatile.

Besides, Laksya also plays an important role in training and assessment of weapon systems and operators. Lakshya can carry two tow-targets on wing-mounted pylons. These tow-targets, which trail the mother aircraft by 1.5 km, not only keep the mother aircraft safe but also enable reusability of Lakshya.

Tow-targets are modular in construction and can be easily configured to mission requirements. They house radar, visual and infrared augmentation devices, and provide realistic aerial threat simulation. Acoustic and Doppler-based miss-distance indicators aid weapon systems performance evaluation. Zero-length launcher and parachute-based recovery systems allow launching of Lakshya from land or ship and its safe recovery on land or sea. Ground control station (GCS) and telemetry station allow pilotless control of Lakshya and real-time data acquisition. Forty-two Lakshya systems have been delivered to the Indian Army after more than 200 trials. ADE is also developing an advanced digital PTA, named Lakshya-2, with enhanced endurance, autonomous and low-level flight capability, salvo flying, and automated test equipment.

Lakshya pilotless target aircraft.

Salient Features: Lakshya		
Flight endurance	:	45 min
Altitude	:	9000 m (clean); 6000 m (tow)
Speed cruise	:	450 kmph
Command range	:	100 km
Launch	:	Zero- length launcher (rocket-assisted)
Recovery	:	Parachute
AUW	:	700 kg

Controlled Aerial Delivery System

An airborne guidance and control system for controlled aerial delivery system (CADS) has been successfully developed by ADE. CADS, in its present form, delivers a payload of 500 kg autonomously to a designated target within 100 m circular error of probability (CEP) using ram air parachute (RAP). RAP can be easily manoeuvred as it can glide and turn. Guidance and control system of CADS automatically steers RAP to a designated point by operating its two lanyards as a function of the cross-track error in the flight path and heading errors, etc. Upon completion of the descent, a flare manoeuver is performed for accomplishing soft landing. CADS

Controlled aerial delivery system.

has the following salient features:

- Manual and autonomous modes of operation.
- Low-cost sensors-based navigation.
- Energy management manoeuvre-based guidance for altitude control.
- Fault-tolerant features against temporary telecommand and GPS link losses.
- Manual override capability.
- Maximum range of 20 km when released from 10 km altitude.

ONGOING PROJECTS

Rustom

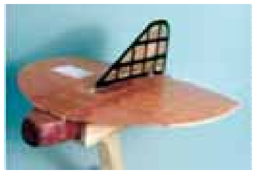
ADE is developing an indigenous, all-weather, medium altitude long endurance (MALE) UAV, named Rustom. Rustom will operate at medium-to-long ranges and gather near real-time high quality imagery and signals intelligence (SIGINT) from areas of interest. Rustom was successfully test flown on 16 October 2010. It flew for over 12 min on its maiden test flight despite inclement weather and landed safely after meeting all its objectives.

Fixed-Wing Micro Air Vehicle

A number of small fixed-wing air vehicles have been developed by ADE in collaboration with NAL. These micro air vehicles are man-portable and have portable GCS command, control and display; image processing capabilities; optical flow-based obstacle avoidance; and horizon detection using computer-vision techniques. Besides, these

Salient Features: Rustom		
Altitude	:	25000 ft
Endurance	:	12-15 h
Speed	:	225 kmph (max.); 150 kmph (cruise)
Command range	:	Up to 250 km
AUW	:	750 kg
Take-off and landing	:	Conventional with external pilot
Payload	:	75 kg

Configurations: Various fixed-wing micro air vehicles



	Black Kite	Golden Hawk	Pushpak
	Geometric Details		
Planform Shape	Inverse Zimmerman	Cropped Delta	Dihedral Delta
Span	300 mm	300 mm	300 mm
Area	0.0618 m^2	0.06 m^2	0.0566 m^2
Aspect ratio	1.45	1.5	1.59
Weight	300 g	245 g	270 g
Wing loading (W/S)	47.62 N/m^2	40.05 N/m^2	46.69 N/m^2
	Aerodynamic Data		
Airfoil	Mean camber of S4083	SM-4308	Modified MH-49
Camber per cent	3.45	3.49	0.7
Cl_{max}	1.3	1.26	1.05
Reynold No.	1,90,000	1,60,000	2,00,000
Lift/Drag ratio	7.5	9.7	7.7
	Prototype Fabrication		
Airframe	Flute Board Composite CFRP & GFRP	Foam and Balsa Wood	Foam and Balsa Wood

vehicles use single-axis tracking system for datalink. Three configurations, viz., Black Kite, Golden Hawk, and Pushpak have been designed, developed and test flown.

Sudarshan

An advanced laser guidance bomb (LGB) kit, Sudarshan, is being developed by ADE to improve the accuracy of conventional 1000 lb class dumb bombs. The guidance kit directs the bomb towards a target, which has been illuminated by laser energy using a laser designator system. The laser energy is reflected from the target and detected by the

Sudarshan—Laser guidance bomb kit.

laser seeker unit on the LGB kit. The seeker provides information on the deviation of the laser spot from the centre line of the detector. The control system processes this information and generates suitable deflections on the canard surfaces to effect changes in bomb trajectory, thereby guiding the bomb to the target.

The development of the kit has matured to the level of guiding the bomb within 10 m CEP from its otherwise 400 m to 1000 m fall-off the target. Indian Air Force has shown keen interest in buying hundreds of these kits. The extension of kit's capability to further increase its range using global positioning system (GPS) INS is going on.

FUTURE PROJECTS

Rustom-H

Rustom-H, a medium altitude, long endurance UAV with multi-mission capability, is being developed indigenously for the Armed Forces. Rustom-H would be capable of: Taking-off from and landing on a prepared runway, carrying payloads up to 350 kg, and operating at altitudes up to 30,000 feet (9.1 km). It can be programmed to fly autonomously in waypoint navigation or in pre-defined patterns up to 35 h and operates on line-of-sight communication up to 250 km and up to 350 km with a relay.

Rustom H.

A variety of state-of-the-art electrooptic (EO) sensors, Electromagnetic Intelligence (ELINT) and Communication Intelligence (COMINT) payloads, SAR or maritime patrol radar (MPR), will be fitted onboard Rustom to provide multi-mission performance capabilities. The technical challenge lies in the design and development of lightweight airframe and systems that operate reliably for long durations.

Unmanned Combat Aerial Vehicle

Aeronautical Development Agency (ADA), ADE, and Defence Avionics and Research Establishment (DARE) are jointly developing an indigenous un-manned combat aerial vehicle (UCAV), named Aura. Flight control system and data link packages of the Aura will be designed and developed jointly by ADE and Defence Electronic Application Laboratory, Dehradun.

Salient Features

- Capable of short run take-off and landing on prepared runway.
- Capability to fly at altitudes of 30000 ft with payloads.
- Manual and autonomous controls, with radar warning receiver, identification of friend or foe, and traffic collision avoidance systems.

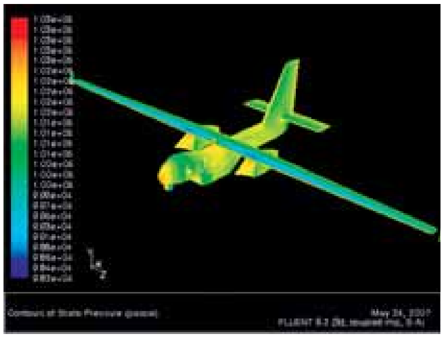
UAV SYSTEM TECHNOLOGIES

During development of Nishant and Lakshya, ADE has developed a large number of technologies in the field of flight telemetry, control system, sensors, and composite materials that have aided in the design, testing, analysis, and manufacturing of UAVs. The technologies developed and implemented in the UAV sub-systems are:

Aerodynamics Design

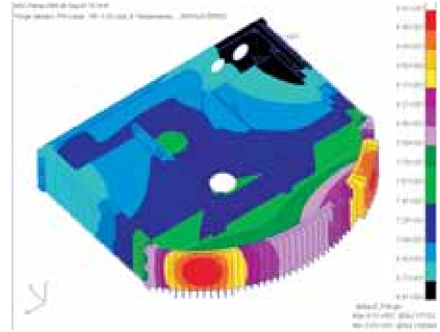
ADE has expertise in aerodynamic configuration design, performance evaluation, and analysis of a UAV using advanced computer-aided design (CAD) tools; powerful computational fluid dynamics (CFD) tools based on Reynolds-averaged Navier-Stokes (RANS) equations, LES and domain name system (DNS) techniques; wind tunnel testing with the state-of-the-art data acquisition systems; and flow visualisation using PIV, PSP, and laser techniques.

Design and development of multi-element airfoil to achieve high



Airframe design.

Wind tunnel testing of Lakshya.

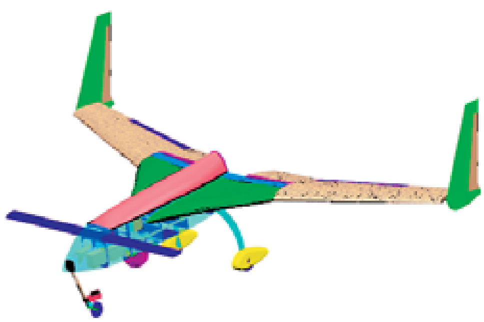


Thermal analysis using MSC/Nastran.

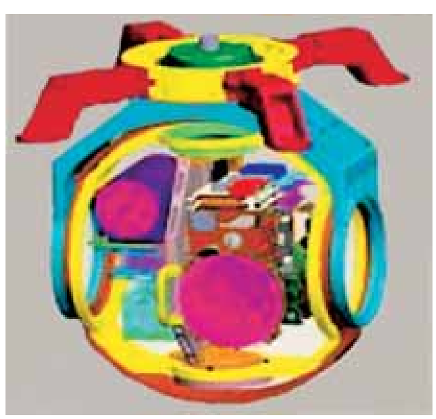
lift resulting into enhanced endurance of UAV has been achieved. CFD capability includes advanced software like Panel code; Euler code; RANS code; Nielson code for store separation characteristics at transonic speeds; propeller design code based on calculus of variation; airfoil design and analysis code; aircraft database generation code; and design optimisation code.

Aero Structure Design

ADE is involved in the total aero structure design including configuration design, equipment layout, sizing of components, and conventional and Finite Element (FE) analysis of airframe components. Expertise has been developed in the fields of aero-elastic studies, impact studies, power plant configuration, and Slosh analysis. Modules are iteratively designed using advanced tools. Structural design and evaluation using composites have been extensively used. Gimbaled payload assembly (GPA) is a high precision optomechanical system used for reconnaissance purpose. A much optimised design has been achieved using latest CAD tools including Pro-engineer and ADAMS. This has been widely used in Nishant and Rustom Projects. All the electronic packages for the UAV programme have been developed in-house carrying out thermal, shock load, and dynamic analyses. Thermal imaging, shock response spectrum test, and environmental test have been conducted as per MIL standards.



Detail designs and 3-D modelling.



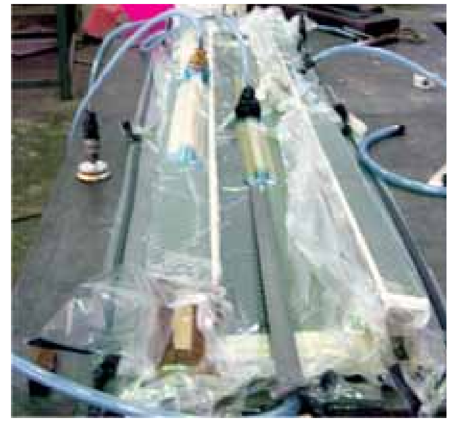
Gimbal system.

Composite Technologies

ADE has developed various grades of syntactic foams for specific aerospace applications like microwave transparent foams (as core material in broadband sandwich radome); electrically-conductive foams (as core material in electronic enclosures); and carbon nanotube-reinforced nano-composite foams, etc. The foams are typically used as the core materials in sandwich configurations designed for different applications and can also be suitably tailored for the same by intelligent choice of chemistry and composition.

Use of improved and environmental friendly non-contact molding processes like resin infusion molding (RIM) and resin transfer molding (RTM) have been mastered. The processes were first validated by process experiments involving point infusion (radial flow) and directional flow (edge flow) techniques for monolithic and sandwich panels and then demonstrated successfully by developing different prototype UAV parts, and finally extended to develop actual UAV components.

Composite technologies (from extreme left top): PTA fairing (front); air-in-take; Luneberg lens; tail fin assembly; different composite parts; PTA fairng (rear).



Resin infusion molding in progress.

Propulsion

Indigenisation of Gas Turbine and Rotary Engines

Development of a jet engine involves a coordinated effort among the designers, certification agency, and the users. Coordinated efforts of ADE have resulted in the development of an indigenous certified airworthy jet engine [Pilotless Target Aircraft Engine (PTAE)-7], which meets all mission requirements of the Lakshya including high altitude tests. Indigenous development of a rotary engine is critical for ADE's UAV programme. A 55 hp rotary, water-cooled Wankel engine has been designed and developed jointly by ADE, NAL and VRDE, and integrated with Nishant. The performance of the engine has been proved in flight trials.

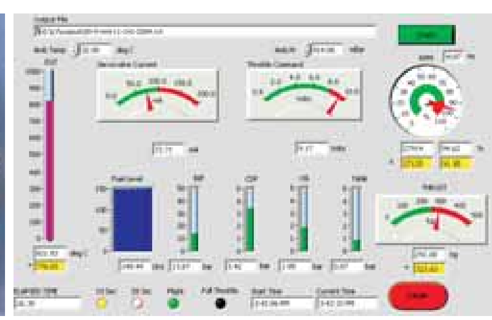
Engine Health Monitoring

ADE has set up test-bed facilities for testing gas turbines, and rotary and internal combustion engines of UAVs. An online data acquisition and health monitoring system (DAHMS) has also been developed by ADE to monitor all engine parameters during engine testing on ground and integration runs. DAHMS displays parameters in red when these engines exceeded their maximum limits during testing. The basic approach of the DAHMS is to collect data of all engine parameters from all the fault-free engine runs at various engine speeds. A baseline signature model has been developed using statistical tools to predict the average and the standard deviations of each engine parameter. Engine test run data acquired online is then compared with the baseline signature of the engine. The online engine parameters are displayed with reference to the baseline signature model indicating the health of the system.

Flight Mechanics and Control Engineering

Design and development of the flight control laws is the most important phase of aircraft development as this ensures the stability and controllability of air vehicle over the entire flight envelope. ADE has established

Indigenous PTA engine (PTAE-7).



Data acquisition system.

facilities to conduct mathematical modelling of rigid body dynamics (6DoF), flexible body dynamics (9DoF), dynamics of electro-mechanical actuators and flight and mission sensors, and atmospheric disturbances. Expertise is available in the error modelling of actuators, sensors, digital implementation effects, and nonlinearities. ADE has evolved and adopted a unique design specification for various unmanned vehicles.

A low-cost, lightweight, moderate-accuracy navigation system has also been designed by ADE. It is one of the first aeronautical systems wherein designers have used 'air data dead reckoning' navigation as the primary navigation system and GPS as the secondary navigation system. ADE is also venturing into the state-of-the-art laser-based inertial navigation system for HALE/MALE UAVs, and miniaturised INS for micro UAVs.

The capability to design guidance system based on pursuit and turn pursuit for aircraft, line of sight for bombs, PN and predictive guidance for targets, has been attained. ADE has capability to design and develop the mission control laws also for various unmanned vehicles. This includes the mission sequence to be followed during vertical launch, terminal homing, automatic take-off and landing, automated waypoint navigation in cruise phase and in recovery. A three-tier mission control structure has been designed with manual mode (layer 1), semi-autonomous mode (layer 2), and fully autonomous mode (layer 3) that helps ground pilot to control the aircraft according to the situation. This mission control law has provision to execute pre-programmed manoeuvres that facilitate its mission sensor focused on the target(s).

Flight Control Software and Hardware

Onboard Flight Control Software for UAVs

The flight control, mission, and navigation program is an embedded software performing safety-critical computations for navigation, guidance, and control functions. It receives inputs from various sensors and ground-generated commands and processes these inputs to compute the control output for the actuators in real-time frame. The flight control software for various UAVs in general helps in the following main functions:

- Automated launch phase.
- Manual and assisted take-off and landing (Rustom).
- Manual flying.
- Heading hold, altitude hold, speed hold and track hold functions.
- Air data dead reckoning navigation with GPS and ground tracker updates.
- Flight during link-loss mode.
- Capability for in-flight mission plan change.
- Low-level flight (50 m) and high G turns (Lakshya).
- Semi-autonomous flight.
- Fully autonomous mode with waypoint navigation.
- Autonomous programmed flight modes.
- Circle program.
- Racecourse program across and along the leg.
- Figure-of-eight program across and along the leg.
- Navigate back home through Get-U-Home mode.

ADE has set-up sophisticated software development facility with tools and infrastructure catering to the entire software development lifecycle.

Salient Features

- Software requirements generation (DOORS/Analyst).
- Software design—Rhapsody Ada developer.
- RTOS–VX WORKS.
- Coding–Green Hills Ada Multi/GNAT Pro Ada.
- CSU/CSC testing —AdaTest 95, C language, simulator/target board.
- Software configuration tool—Synergy.
- TARGET-Zilog 8002/MPC 555/ MPC 7410/7448.
- HOST platform—PCs, PC servers, and SUN server with thin clients.

Actuators

ADE has designed and developed electromechanical actuators for various UAV applications like engine



Flight control actuator.

throttle control, and control surface actuators. The first indigenously designed, developed, and produced actuators are rotary type and have been used in Nishant. These are inherently simple and reliable and built around brush dc motor, spur gears, and potentiometer as a position sensor.

The experience gained from these actuation systems has been used in developing high-power actuator for Lakshya successfully. An integrated actuator with controller, motor, gears and position sensor packed in a compact housing has been realised.

Flight Control Computers

ADE has designed, developed, tested and qualified highly reliable flight control computers (FCCs) for unmanned aircraft.

Flight Control Electronics for Lakshya

Flight control electronics (FCE) is built with analog electronics. The FCE carries out the pitch, roll, yaw compensations, throttle control, and recovery-initiation functions.

Integrated Digital Flight Control Processor for Lakshya-2

Integrated digital flight control processor (IDFCP) is a full-authority compact simplex hardware that caters to the computational and various interface requirements with other sub-systems. The integrated package performs flight control and mission navigation functions, telemetry and ranging functions. The package has provision for GPS, Microelectromechanicalsystems (MEMS) sensors, and other real-world interfaces also.

The flight control functionality is performed by a 32-bit PowerPC (MPC 555) operating @40 MHz. The telemetry functionality is performed by a 32-bit Power PC (MPC 860) @66 MHz. Autonomous handlers have been provided for GPS, heading and Radalt (altimeter) interfaces.

The package provides for fault logging through non-volatile random access memory (NVRAM), built-in-self-test (BIT) and power-on-self-test (POST) features.

Integrated Avionics Package for Nishant

Integrated avionics package (IAP) is a full-authority digital FCS with a limited authority hot standby redundant analog backup unit. It comprises a digital flight control and mission navigation computer (FCMNC) based on Z8002 processor with analog backup and recovery logic, encoder-decoder processor based on 80C186 for pilot command interface, GPS with microcontroller 87c51 interface, air data sensors with necessary signal processing circuitry, interfaces to payload processors, and power supply modules that generate various power supplies for onboard circuitry and sensors.

Open System Architecture-based Flight Control Computer for Rustom

Rustom flight control computer (RFCC) is a duplex flight control computer with advanced redundancy management based on state-of-the-art PowerPC MPC7448 processors working on 1GHz. The computer is designed on two

Flight control electronics for Lakshya.

Integrated avionics package for Nishant.

Flight control computer for Rustom.

Air data unit.

Baro switch unit.

independent VME back-planes enclosed in single chassis with hardware cross strapping to ensure dualisation of simplex inputs. The Operation flight program (OFP) software located in the user Flash memory and a separate boot flash holds the BSP utilities and the operating systems.

Para Flight Control Computer

Para flight control computer (PFCC) is a simplex line replacement unit (LRU) designed to control and navigate the parafoil to the desired landing point (DLP). The computer derives the power from the onboard battery of the parafoil system. All the required power supplies from the 28 V are derived using the dc-dc converter in-built with the electromagnetic interference (EMI) filter. This system uses the state-of-the-art floating point PowerPC controller based on free-scale MPC555 operating at 40 MHz with peak processing power of 52 MIPS.

Sensor Packages

The air data unit provides the barometric altitude and indicates air speed of Lakshya. The unit provides electrical outputs linearly proportional to altitude and indicates air speed of the aircraft. These outputs are used in FCS and also tele-metered for indication to the pilot on ground.

Baro Switch Unit

Baro switch unit is used for controlling the deployment of the main parachute at a pre-determined altitude during the recovery of Lakshya. It prevents the deployment of parachute above the pre-set altitude. This unit provides logic '0' or '1' output for barometric height above or below the pre-set altitude, respectively. Altitude can be pre-set to any value; normally set at nearly 1500 m.

Antenna Design and Computational Electro-magnetics

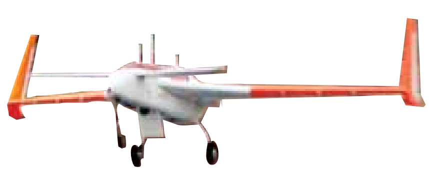
ADE has achieved self-sufficiency in airborne and ground antennae development, aircraft-mounted antenna pattern studies, and radar augmenters development with the antenna location optimisation. ADE has also established the computational electromagnetics facilities, which include method-of-moments (MoM)-based IE3D, finite difference time domain (FDTD)-based fidelity, FEM-based HFSS, and designer software. Various passive and active radar agumneters have also been designed and developed by ADE.

Salient Features: Sensor Packages

Input supply voltage	:	$\pm$28 V ($\pm$ 4 V dc)
Input current	:	100 mA (max.)
Altitude range	:	0 m to 12000 m
Air speed range	:	0 kmph to 1300 kmph

Salient Features: Baro Switch Unit

Input supply voltage	:	$\pm$12 V ($\pm$1 V dc)
Input current	:	50 mA (max.)
Altitude range	:	0 m to 12000 m
Altitude output	:	0 V to 5 V ($\pm$ 0.1 V)



Wrap around.

Three-in-one antenna.

Slotted blade.

Monopole.

Antenna pattern studies.

These augmenters have been used as payloads or imbedded into the structure of the aircraft itself to enhance the radar cross-section of the UAV.

Ground Control Station and Associated Equipment

Ground control station (GCS) is used to track, control, and monitor the UAV. It also helps in mission planning and validation, payload information exploitation and system diagnostics. The GCS receives telemetry data and generates the parameters display and trajectory display. The parameter display provides the status of sub-systems and attitude of the aircraft. The trajectory display provides the flight path of the aircraft on a geographical map of the area, where the mission takes place.

ADE has developed GCS for long endurance operation with full redundancy for all the systems containing features like relay UAV operation capability and intra-operable console configuration. Raster and vector display map with 3-D capability, and structured intelligence database for system fault diagnosis reporting and capability. External pilot technology with safe hand over/take over features, standardisation of system interface for better interconnectivity between various stations, and integrated voice link with command and telemetry, are the important features.

Ground control system displays UAV's flight path and parameters.

Radio Frequency Packages

Some of the radio frequency (RF) packages designed include: Fixed-frequency datalink for UHF command uplink, and P and L band telemetry downlink; and FPGA-based PCM encoder to transmit the telemetry information in PCM serial stream. Besides, the GCS operates in L band to track the UAV during its flight.

Encoder/Decoder Unit: The encoder/decoder unit digitises the commands and digitally modulates the data for transmission. The unit also demodulates the data received from the aircraft and sends the data to the processor for display.

Range Unit: The range unit determines the slant distance of the aircraft from the GCS.

Transmitter: The transmitter transmits the modulated signal from the EDU over UHF.

Receiver: The receiver receives the radio frequency signal transmitted by the aircraft over L band. The baseband signal is sent to the EDU for demodulation.

Tracking System: The tracking system tracks the Lakshya during its mission. The tracking system consists of the antenna control unit, drive unit and antenna. It provides the bearing information to the processor system.

Target Group Set: The target group set is used for evaluating the command links and operation of the GCS sub-systems before the Lakshya mission. The target group set consists of telecommand sub-systems used in the aircraft.

The latest UAVs have programmable data links designed for UHF command and L and S band telemetry downlinks. All RF sub-systems have been designed with built-in-test equipment (BITE) facilities for monitoring the health parameters of the sub-systems. Radar altimeter information is used during the low-level flights of Lakshya. GPS receiver has been used to give the coordinates of Lakshya and GPS/DF beacon system has been developed to locate the UAV after the recovery. Two ground tracking systems—one on L band and the other on S band— have been developed to track the UAV during the flight.

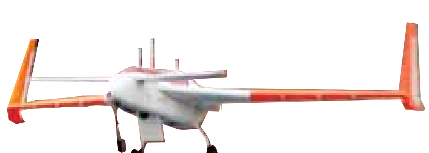
There are ongoing R&D activities like development of FPGA-based QPSK transmitters, where techniques like turbo-encoding, digital video compression, high efficiency linear power amplification, etc., are being studied. The existing telemetry/video links between UAV and GCS are analog in nature using frequency modulation. The FPGA-based design has the advantage of ease of upgradeability and portability. Moreover, it is immune to obsolescence unlike the ASIC-based solution. Without changes in the hardware, complete modulation design can be changed to incorporate any future design changes.

Radio frequency packages (clockwise from top right): Receiver; antenna with tracking mechanism; encoder-decoder unit; and transmitter.

Circuit-level, modular-level, and sub-systems-level designs are also being carried out for different projects. Such activities involve designing of modules like wideband amplifiers, different types of microwave filters, couplers, combiners, synthesisers, low-noise amplifiers, etc., using high-end design tools like the ADS design software. It also involves design of baseband circuits like FM/AM demodulators, down-converters, up-converters, active filters, etc., and overall sub-systems-level designing of transmitters and receivers.

Flight Data Acquisition and Processing

The flight telemetry data is very important to monitor the health of UAVs. Flight data acquisition (FLYDA) and processing system is state-of-the-art mobile world class facility for ground telemetry data reception, storage, and processing and display. ADE has developed two such facilities to provide ground telemetry



Flight data acquisition and processing unit.

echo signals are picked up by the airborne system and then telemetered to the GCS in the real time. The Doppler signal is processed at the ground station, which displays the results to the users in the real time.

Gimbal System

ADE is in the forefront of development of stabilised gimbal payload assemblies (GPA) for the past two decades. As a part of its UAV programme, ADE has developed two-axes two-GPA for medium altitude Nishant air vehicle. These GPA carry single EO payload as well

support for the present and future projects. Airborne data relay platform is used for acquiring data from low-flying UAVs and to re-transmit it to the ground station. Two ground stations and ADE are linked through satellite communication. Equipment are housed in rugged EMI/EMC shielded shelters for transportation.

Payloads and Image Exploitation

Miss Distance Indicator System

ADE has developed two types of scoring systems: Doppler miss distance indicator (DMDI) and acoustic miss distance indicator (AMDI). The DMDI is used extensively for target practice applications. The airborne DMDI operates on FM–CW Homodyne principle. The AMDI picks up the shock wave generated by the supersonic projectiles. The target

Ground system.

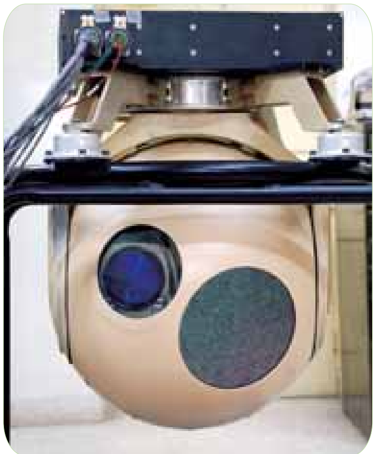
Acoustic miss distance indicator.

Doppler miss distance indicator.

Salient Features: Doppler miss distance indicator and acoustic miss distance indicator.

Specifications	DMDI	AMDI
Principle	FM/CW Radar	Acoustic
Frequency	1.7 GHz	NA
Transmitter power	1 W	1 W
Modulation frequency	1 MHZ	6 kHz
Range dependence	Small cross-section	Shell speed
Miss distance	Up to 15 m for shell of size 105 mm Up to 40 m for typical missile	0-20 m
Accuracy	15 per cent	15 per cent
Relative velocity	0.5-4 Mach	> 1 Mach
Telemetry range	25 km	25 km

Salient Features: Various Gimbal stabilised payloads



Gimbal payload assembly Mk 4.

	GPA Mk 1	GPA Mk2	GPA Mk 3	GPA Mk4
No. of axes	2	2	2	2
No. of gimbals	2	3	2	4
Size (mm)	470 dia 700 ht	320 dia 450 ht	370 dia 550 ht	400 dia 550 ht
Weight PL + Ele (kg)	40	15	35	45
EO payload	LRF + DLTV LRF + L3TV FLIR	DLTV L3TV	FLIR + DLTV DLTV + LRF	LRF + DLTV LRF + L3TV FLIR
Stabilisation accuracy (μ rad)	Better than 100	Better than 100	Better than 100	Better than 30

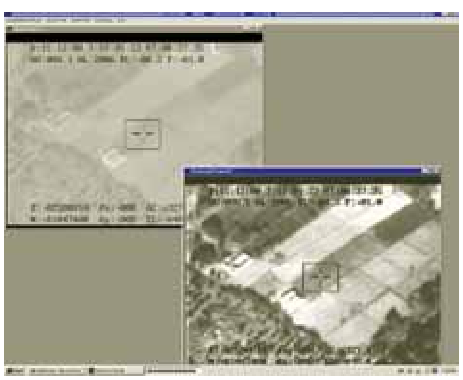
as dual EO payloads (DTV + FLIR). The target acquisition ranges of two-axes two-GPA are limited to 5 km for a tank sized target. In a continuing effort to improve the target acquisition capabilities, for both manned and unmanned platforms, ADE undertook the design and development of precision stabilised EO payload system for medium range target acquisition and tracking during day and night. Stabilisation accuracy of the GPA is better than 30 μ-rad.

The system, suitable for manned and unmanned aircraft, is capable of detecting and recognising a tank sized target at a range of 20 km and 8 km, respectively. Three-axes motion simulator facility (TAMS) to test the stabilisation performance of GPA has been set up.

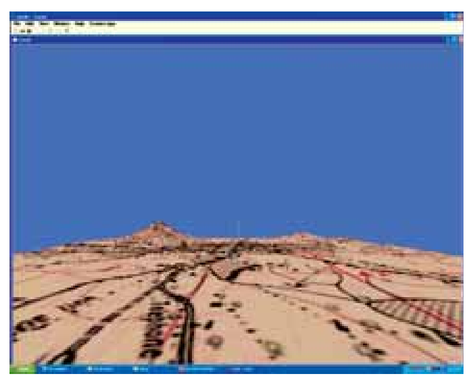
Ground Image Exploitation System

ADE has developed adaptive image pre-processing algorithms for real-time enhancement of low contrast aerial imagery, mathematical models for computing the ground location of targets and terrain measurements, and a combination of the two for various applications. The ground image exploitation system has been successfully installed in an advanced GCS of Nishant to acquire, store, retrieve, process, analyse, interpret, display, and disseminate information from imagery during UAV mission.

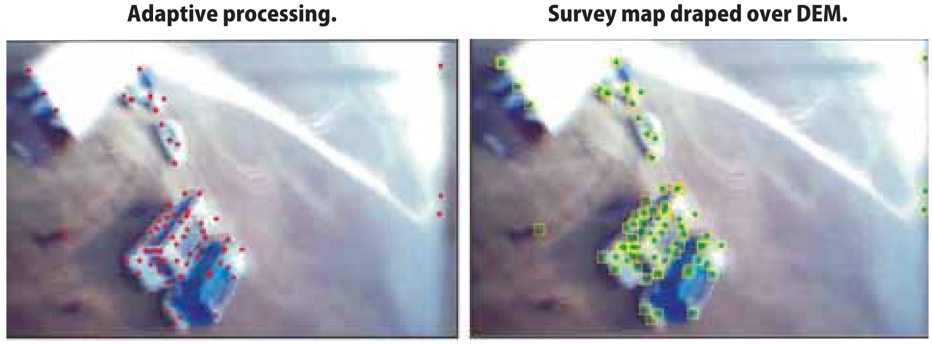
Registration and mapping for enhanced understanding of images have been done. The aligned images



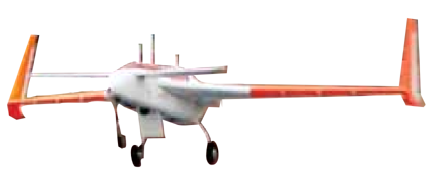
Adaptive processing.



Survey map draped over DEM.



Feature-based tracking.



can be (a) stitched together to provide a panoramic view, (b) compared to detect changes, or (c) blended to generate higher resolution images. Mapping involves finding common coordinates among various data sets such as aerial and satellite images, survey maps, digital elevation model, etc., for providing enhanced intelligence/interpretation.

Feature-based techniques have been used for understanding scene and tracking objects. Points with distinct characteristics in images are selected and tracked through the video. Flow of feature vectors provides motion estimation, likely collision with an object, etc. Combined with rule-base, this can help to identify abnormal activities in the region.

UAV Simulator

A real-time simulator has been developed at ADE to support the design and development phase of the Rustom-1 as well as for training the external pilot during take-off and landing. During the design phase of the UAV, the simulator is used for verifying the claw for take-off/landing and cruise. In effect, the handling quality of the air vehicle can be evaluated itinerantly.

The dynamics for ground handling, undercarriage and nose wheel steering are simulated and integrated with claw. In the external pilot training mode, the pilot can be trained for carrying out precise take-off and landing under all weather conditions including crosswinds.

In the system design, PCs are configured to meet the specific requirements. All the PCs are rack mountable and individually configured with LINUX OS to meet the processing and graphic requirements. RT LINUX serves as RTOS in the host computer. The visual cues and audio cues are generated using digitally recorded engine noise. Commercial-of-the-Shelf (COTS)-based data acquisition system provides an interface between the various sub-systems and EP controls. A three-channel visual system designed and developed using high performance PCs, with advanced graphics processors, provide the requisite visual cues for the external pilot. The visual scenery is projected seamlessly on a cylindrical screen with a field of view of 180° in azimuth and 40° in elevation.

Distributed computing architecture has been used for the simulation of various sub-systems of the Rustom-1 simulator. The system architecture is modular and configured around a suitable mix of PCs and custom-built hardware (wherever required). The inter sub-systems communications are effected through deterministic real-time communication link. Functional independence and real-time communication are the key factors in arriving at optimal system architecture.

Development of Hardware in Loop Simulation for Flight Control Systems of UAV

ADE has developed a distributed architecture-based hardware in the loop simulation (HILS) test facility meant for the complete testing of the FCS before being integrated on to the UAV. It is built using high-end industrial PCs with RT Linux as the operating system. The development telemetry link of the FCC can be monitored in the HILS during various tests. This is done in order to verify that the OFP is executing properly as well as to verify the contents of the telemetry data that will be transmitted to the ground during the development trials of the FCC.

HILS hosts the real-time software comprising 6DoF aircraft models, software models of various LRUs, an integrated test environment system software, databases, etc. The architecture supports multi-rate iteration as well as multi-node execution of the various real-time simulation models with inter-node communication. It also supports over ordinary Ethernet lines instead of shared memory cards in real-time. HILS allow connection of real or simulated LRUs, analog and digital data acquisition, monitoring and simulating of all the I/Os as well as the serial data channels of the FCCs and downloading/uploading/verifying of the operational flight program of the FCC. A graphics display system provides critical information in near real-time with a front-end host

Hardware-in-loop software system.

Three-axes motion simulator.

computer for controlling the entire operation of the HILS test facility. HILS is being used extensively for all end-to-end tests of the FCS hardware and software. HILS also includes a control station which comprises various input and output devices like different types of switches, indicators, joysticks, etc. This enables the pilot of the UAV to exercise the RFCC hardware and software in closed-loop tests. The control station also has near real-time display station with user-friendly GUIs and touch panels for effective interaction by the pilot with the system.

TAMS is a major system in the R-HILS that provides a platform for mounting various rate sensors of the FCS. TAMS is controlled by the HILS software in closed loop operation.

Quality Control

Quality control (QC) plays a major role in success of any product. All UAV systems go through tough quality checks before going for integration. Inspection at different stages ensures quality in every phase of development.

All raw materials used for various projects are evaluated for quality by non-destructive testing (NDT), dimensional details and sub-assembly. QC of vendor fabricated metallic and non-metallic components and processes are checked at the vendor premises itself. Bare and populated printed circuit board (PCB) checks, LRU level checks, and cable loom clearance, are carried out before clearance for integration. Reliability analysis activities like hardware reliability, reliability apportionment, reliability prediction, reliability estimation, failure mode and effect analysis (FMEA) or failure modes, effects and

Optical zoom instrument for inspection of PCBs (left). Actuator stiffness test (top) and copper thickness measuring instruments for PTH and surface PCBs.

critical analysis (FMECA), and fault tree analysis (FTA) are carried out.

Integration

Mechanical assemblies are evaluated for quality at different stages of mechanical integration and various checks are carried out on airframe before clearance for integration. Avionics system integration is a mandatory and vital phase of an aircraft development lifecycle, since it brings out the important issues relating to the interfacing of LRUs developed by the various workcentres. This process ensures safe and reliable accomplishment of the mission in the most efficient way.

Avionics system integration, being a multidisciplinary task, calls for the contributions from the highly skilled engineers and scientists, who have knowledge and understanding of the system. Flight line tester (FLT) is the first step towards attaining automation in testing of UAVs. Avionics preparation vehicle (APV) is the station to give clearance to launch the UAV and to function as a remote video terminal (RVT) in totality.

Flight Testing

Evaluating an air vehicle for its performance is the most important stage in its development. Testing of aerial targets is carried out at DRDO's Integrated Test Range (ITR), Chandipur. For tactical UAVs, a range in Kolar, Karnataka, has been established and a new aeronautical test range at Chitradurga is under development. These ranges are equipped with latest equipment like radars, EO thermal scanning, CCTV, and high-speed cameras for tracking and evaluation of UAVs.

SYSTEMS FROM SISTER DRDO LABS/ESTTS

The design and development of UAV systems is a multidisciplinary

Mechanical integration.

Flight line tester.

process. The following DRDO labs/estt are also involved in the development of different sub-systems:

Warhead: Armament Research and Development Establishment, Pune.

Luneberg Lense: Defence Materials and Stores Research and Development Establishment, Kanpur.

Pyro Devices and Booster: High Energy Materials Research Laboratory, Pune, and Advanced Systems Laboratory, Hyderabad.

Datalink for Nishant: Defence Electronics Application Laboratory, Dehradun.

Recovery Parachute: Aerial Delivery Research and Development Establishment, Agra.

RCS Measurement: Defence Laboratory, Jodhpur.

Launcher for Nishant and Lakshya 2: Research and Development Establishment (Engineers), Pune.

While various sub-systems are being produced by private vendors, QC, integration, flight tests are being carried out by DRDO.

PRODUCTION PARTNERS

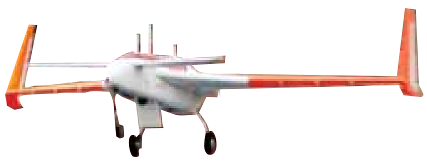
Production of UAVs for the Services is being done in partnership with Defence PSUs and private vendors. Technology for Lakshya has been transferred to HAL. Besides, some other production partners are: Bharat Electronic Limited (BEL); Bharat Dynamics Limited (BDL); High Energy Batteries (HEB); Electronic Corporation of India Limited (ECIL); and Ordnance Factories.

Lakshya recovery.

Warhead.

Luneberg lense.

Thrust vector control booster.



FUTURE SCENARIO

The potential of UAVs is very vast. In 21st century, DRDO is committed to deliver state-of-the-art UAV systems to the Indian Armed Forces. The technologies described above are the base for the future UAV development programmes. Futuristic programmes of DRDO include UCAV, micro and mini, multi-role, and solar powered UAVs.

Technology predictions for the next decade envisage 50 per cent increase in endurance, silent engines, self-repairing, and damage-compensating structures with real-time monitoring of structural health, rotorcraft of high speeds, multichannel data acquisition systems, full automatic control of flight and mission, etc.

Nishant (top) and Lakshya launchers.

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Technology Focus focuses on the technological developments in the Organisation, covering the products, processes, and technologies.

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