ScienceScope

Quarterly publication of the CSIR
South Africa's Council for Scientific and Industrial Research
Volume 1 Number 5 December 2006
www.csir.co.za

AEROSPACE

CSIR
our future through science

Volume 1 Number 5 December 2006

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AEROSPACE

NEWS

Dr Kamalluddien Parker, Philip Haupt and John Wesley

Overview

South Africa has a long and proud history of aerospace innovation and development, with the CSIR being an inextricable part of this through its many years of novel aerospace research and development.

An overview: Honing the CSIR's role in aerospace

By Philip Haupt, Dr Kamalluddien Parker and John Wesley

By the very nature of the skills and technologies involved, the world-wide aerospace industry is a powerful driver of innovation across the industrial base.

A flourishing and competitive aerospace industry is regarded by most countries as an essential element for a secure and prosperous nation. The European Union and the USA have extremely large aeronautical and space industries that are critical and pervasive generators of technology, wealth and expertise. By the very nature of the skills and technologies involved, the world-wide aerospace industry is a powerful driver of innovation across the industrial base.

South Africa has a long and proud history of aerospace innovation and development, with the CSIR being an inextricable part of this through its many years of novel aerospace research and development (R&D). The CSIR is seen as a key player in the South African aerospace landscape and a custodian of unique world-class aerospace R&D skills.

As incubator of all-encompassing technologies, outcomes of advances in the manufacture and operation of aerospace systems impact on society at large. This could be in the improvement of the carrying capacity of commercial transport aircraft, the avionics capabilities of military fighter aircraft, or additional applications in other areas such as the automotive and power generation industries.

Aerospace capabilities are essential to national safety and security. A large proportion of products in the aerospace sector has direct defensive and offensive applications, and is thus instrumental in maintaining sovereignty, force projection and peace keeping, as well as in assistance in disaster relief.

Internationally, extreme demands are placed on the industry to achieve suitable levels of quality, safety, efficiency, certification and R&D. Success in terms of these measures will not only position South Africa's aerospace manufacturing industry, but also reinforce the role that local universities and science councils can play in creating the future technologies required.

The aerospace sector in South Africa consists of stakeholders in the general aviation sector, as well as commercial and military aviation. While the applications vary, the underlying technology is inherently common to each of the sector components. Any outward-orientated, nationally focused intervention geared towards increasing the market share of the local industry in the global supply chain, should therefore recognise that one of the optimal methods of engagement is through the establishment of technology platforms that can impact on the entire aerospace sector.

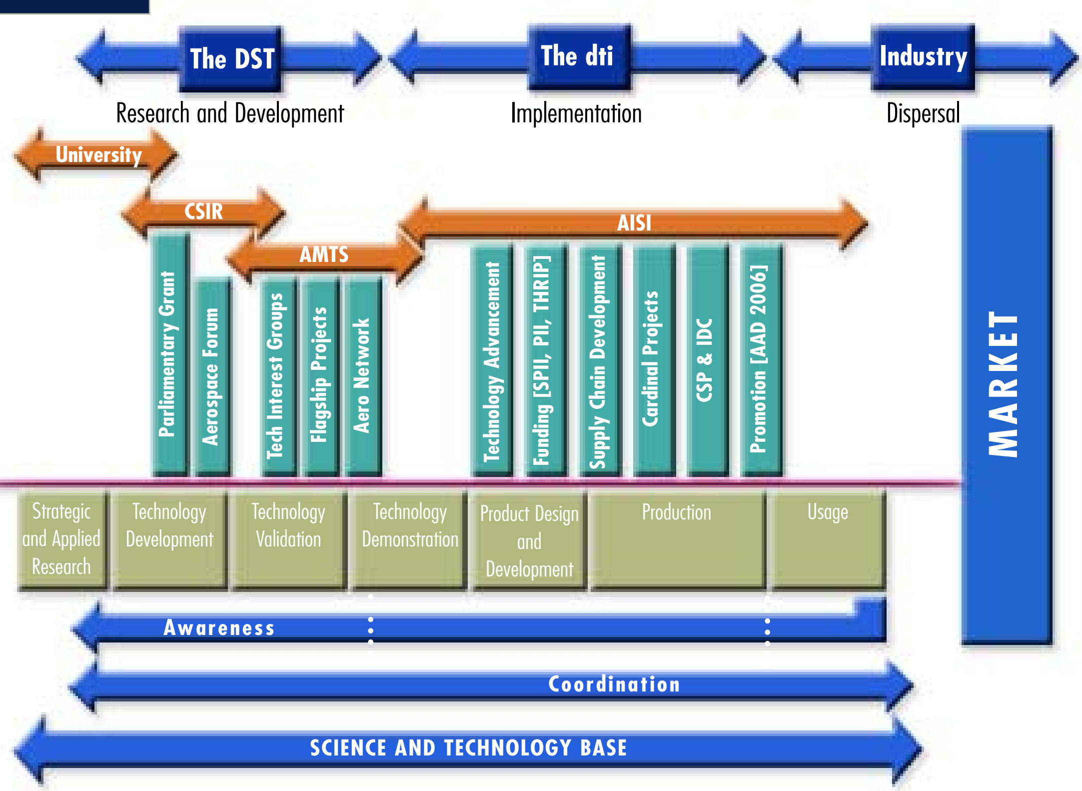
The space component of aerospace also relies to a large degree on similar basic technologies. These include advanced light materials, high-resolution sensors and advanced electronics. Of the 26 technology areas designated by the European Space Agency, 18 are covered to varying degrees within CSIR Defence, Peace, Safety and Security, CSIR Materials Science and Manufacturing and the CSIR Satellite Applications Centre. CSIR Built Environment is also active in a sub-set of the technology areas.

The nature of the technology is pervasive and can, as such, be refined to fulfil the harsh environmental parameters required in both near and outer space. Technologies focusing on the aerospace sector are also likely to find application in the automotive and information and communications technology (ICT) areas.

The two largest aerospace companies in the world – Boeing and Airbus – control the largest share of both the civilian and military aerospace markets, either exclusively or through mergers. Of the most significant market needs dictating their position are requirements for on-time delivery and technological advantage. Traditional military-focused aerospace companies – such as BAE, Dassault, SAAB and Eurocopter – also experience similar drivers in their markets, given that the lines between defence and civilian applications are being removed and programmes are being driven along technology lines only. The A400M military transport aircraft is a typical example of this.

Reduced time-to-market of an aircraft that has superior technology would provide significant market advantage. Thus, there is a coupling of the needs of the original equipment manufacturer (OEM) for novel technologies that characterise new aircraft, with the need to integrate all components into a useable system quickly and efficiently. This will provide customers with the competitive advantage they require in their aggressive market or military application. Driven by these and other needs, OEMs in the aerospace sector have followed the example of counterparts in the automotive sector in relegating themselves to system integrators. This allows a country like South Africa to align with these needs. Any potential tier supplier to these OEMs must therefore identify

Below: *Value chain from R&D to implementation and dispersal to market*



with and adapt to the constraints of their tier group, as well as to the timescales of the OEM.

The opportunities created by the drive towards system integration are being taken very seriously by the South African government. It is striving, through relevant government departments, the CSIR and others, to ensure that all South Africans benefit from a sustainable, growing, empowered and internationally recognised aerospace industry by 2014.

Three government departments are actively involved with the CSIR in achieving this, namely the Department of Defence (DoD), the Department of Science and Technology (DST) and the Department of Trade and Industry (the dti). Each department plays a unique, interlinked role with the CSIR, who is the custodian on their behalf of relevant technology projects and programmes, such as the Advanced Manufacturing Technologies Strategy (AMTS) and the Aerospace Industry Support Initiative (AISI). This "value-chain" extends all the way from basic research to actual usage.

The technology validation and demonstration role is undertaken by the AMTS with its focus on advanced manufacturing technologies, advanced product technologies, ICT, logistics and advanced cleaner production technologies. These technologies cut across the automotive, aerospace, textile and clothing, metals, chemical and cultural craft sectors. The areas of light materials include composites and light metals, such as titanium, magnesium and aluminium. Light metals initiatives focus on the reduction of aircraft structural weight and automobile weight, while increasing local content.

Another priority technology flagship is advanced electronics, which includes sensor development, technology and fusion. Sensors play an important role in guidance and control systems for land, sea and air-based vehicles. Also included in advanced electronics is miniaturisation technology for gyroscopes and accelerometers and, in general, micro-electro-mechanical systems.

The technology advancement and product implementation role is undertaken by the AISI, which focuses on advancement of technology developed through the AMTS and its partners, such as the CSIR, in the local manufacturing industry where products need to be made correctly and efficiently. The AISI considers developing technologies and processes around supply-chain optimisation, system integration and optimisation, manufacturing infrastructural support and the management of large cardinal projects, such as the A400M military transport aircraft. Integral to this is the creation of relationships with the relevant international OEMs.

The CSIR is uniquely positioned to cover the technology overlaps between commercial aviation, space missions and military operations. The DoD funds research in a number of aerospace-related fields, such as aerothermodynamics, computational fluid mechanics, aerostructures, optoelectronic sensors and systems, radar and electronic systems. The DoD also supports the development of test and evaluation technologies covering wind-tunnel testing, material and structural testing, aircraft performance and handling test and evaluation, radar systems test and evaluation and optronic system test and evaluation. Much of this is then used to develop dedicated advanced test and evaluation facilities in support of commercial and military industries.

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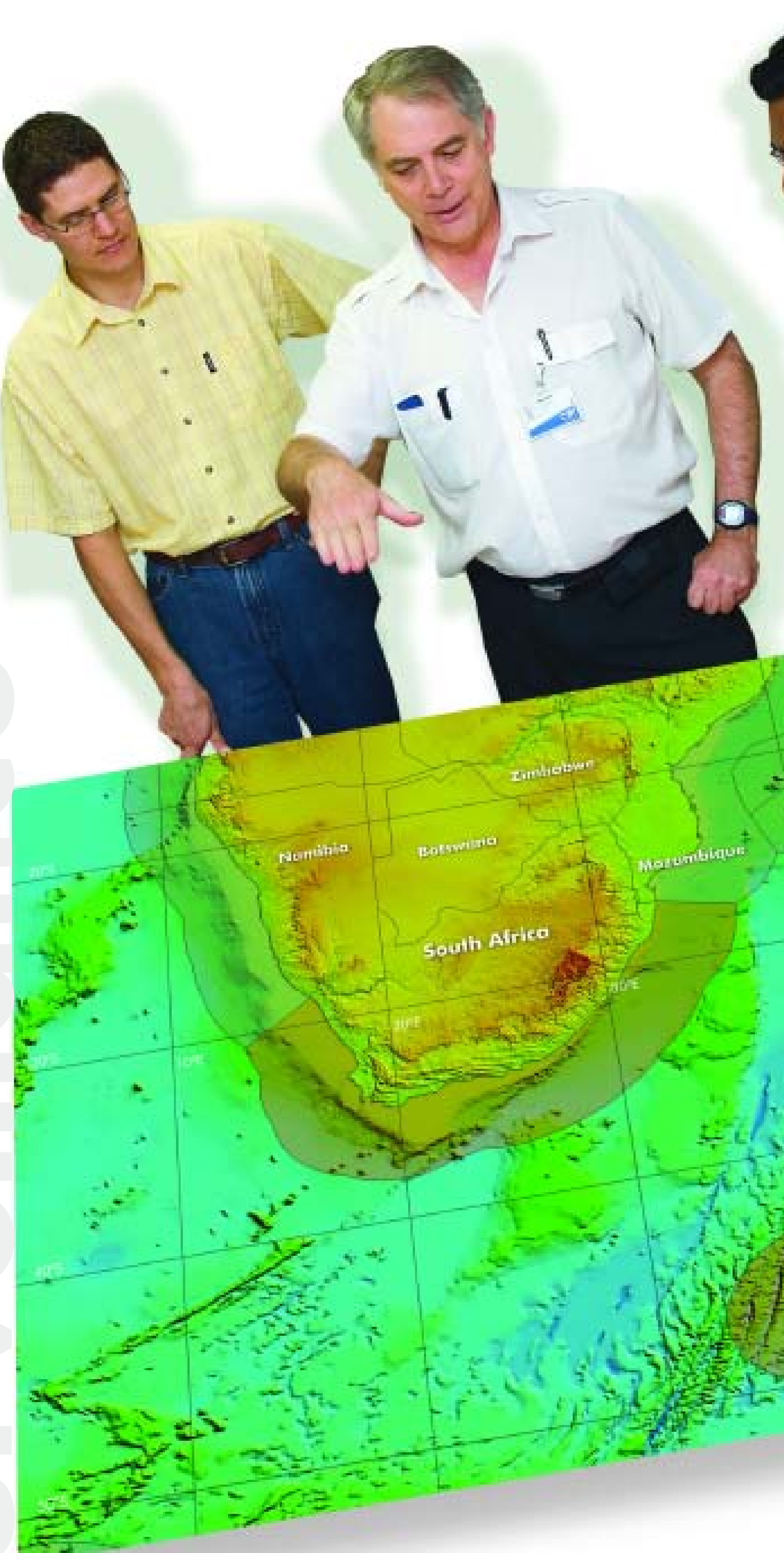
Aerospace technology is a pervasive base that is key to the future. The DoD capabilities developed for aerospace are often used for other non-aerospace sectors of industry and society. Examples include:

- Computational fluid dynamics is used extensively by the mining and metals industries
- The structural vibration analysis method used for aircraft flutter prediction is applied successfully to large industrial plants
- Process modelling techniques developed for casting of turbine blades are widely used to model casting processes in the automotive and metals industries
- Materials and structural modelling techniques developed for turbine blade design and life assessment are extensively used in the metals industry
- Wind-tunnel testing supports renewable energy research by testing wind turbines
- Advanced aerostructures technologies have been used to establish South African companies that became world leaders in advanced automotive carbon fibre component◊
- Sub-system manufacture and aerothermodynamic capabilities are used to develop advanced solar energy technologies.

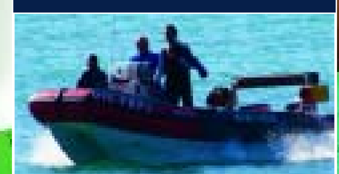
FACTS

- The South African Air Force is the second oldest in the world.
- The Aeronautical Society of South Africa – established in 1911 – is one of the oldest learned societies, promoting "the art and science of aerial navigation".

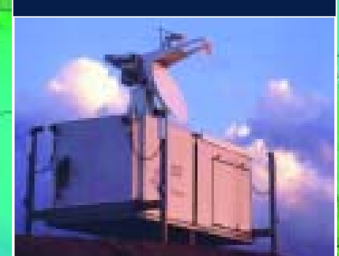
surveillance



Protecting our waters: Francois Anderson (centre) with his AwareNet colleagues, Ferdie Potgieter and Yunus Abdul Gaffar



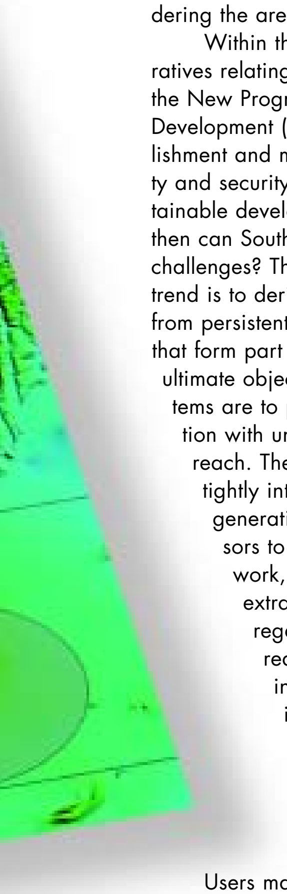
Small rigid inflatable boats are used for poaching, smuggling and even sometimes for piracy and terrorism



The Fynmeet instrumentation radar is used to measure the radar characteristics of objects of interest in their natural environment as part of research into the automatic detection of these objects by means of radar sensors

Persistent surveillance to protect our waters

By Francois Anderson



South Africa and its surrounding maritime zones are continuously being threatened by activities such as illegal fishing, illegal immigration, smuggling, piracy, terrorism and oil pollution. In most cases, these activities are difficult to observe, as these forces choose to work at night, in bad weather or in deserted places. The country has a 1,5 million square kilometre economic exclusion zone (EEZ), but its naval and coast guard forces available for patrolling this vast area are relatively small considering the area to be secured.

Within the broader context of imperatives relating to the continent of Africa, the New Programme for Africa's Development (NEPAD) identifies the establishment and maintenance of peace, safety and security as a prerequisites for sustainable development in Africa. What then can South Africa do to meet these challenges? The modern international trend is to derive situational awareness from persistent area surveillance sensors that form part of a system of systems. The ultimate objectives of the high-level systems are to provide real-time information with unprecedented richness and reach. The richness is achieved by tightly integrating a variety of new-generation, high-performance sensors to form an information network, fusing the sensed data, and extracting enriched information regarding the situation. The reach is achieved by segmenting the resulting information into classes of interest for various user groupings and providing only that part of the real-time information that is of interest to each user group.

Users may then develop the requisite situational awareness based on insight into that part of the situation that is their responsibility to control. Based on this insight, predictions of how the situation will develop and quality decision-making regarding deployment of forces to influence the situation become possible to achieve the desired outcome optimally.

What is AwareNet?

The CSIR's plan to develop a science and technology (S&T) capability in line with international trends for persistent area surveillance has been dubbed AwareNet. Based on this capability (knowledge, facilities and processes), solutions can be developed that will provide information derived from real-time, persistent surveillance to users in the state's peace, safety and security related agencies.

This information should allow users in these agencies to develop real-time situational awareness regarding the presence of entities in their areas of interest, their position and movement, their classification and identity and their activities and intentions. Slowly changing information that provides the context and thereby enhances the extraction of meaning from the sensed information will be seamlessly integrated with it. Examples include maps providing geographic and weather information.

S&T required for AwareNet

The AwareNet programme requires S&T capabilities and focused research and development (R&D) in the systems, aerospace, electronics and computer engineering as well as in the information science and applied physics and mathematics fields of knowledge. A substantial part of the required capability has been developed in South Africa over the past 30 years with military funding across the complete value chain from academics through research institutions, test ranges, acquisition management, to industry and some parts of the user community. The proposed ultimate outcome of the AwareNet S&T capability development will go a long way to utilising this capability and converting it into a major new cluster fostering South African economic growth, job creation and international competitiveness in products required for national border surveillance and control. Five major areas of technology have been identified as underpinning a capability in persistent area surveillance and remote sensing: stratospheric airships; radar sensors; electro-optical sensors; radio frequency surveillance sensors; and data fusion and information extraction algorithms. In many of these areas the CSIR and its partners at universities and in industry have the required background and infrastructure. However, these need to be refocused and expanded to establish the new capability.

Potential AwareNet users

It is planned that the AwareNet S&T capability development be focused to support a specific launch application, namely a maritime area surveillance system, first for the coastal regions of South Africa, then for the South African EEZ and later still for the extended South African EEZ (which will include the rich fishing grounds of the Agulhas Plateau and Mozambique ridge) and the southern African region.

South African users who will benefit from the AwareNet capability are the country's peace-keeping forces, law enforcement agencies, environmental protection agencies and disaster management agencies – the Department of Defence (South African Navy, South African Army, South African Air Force, Defence Intelligence and Joint Operations); the South African Police Service; the Department of Transport; and the Department of Environmental Affairs and Tourism's Marine and Coastal Management. The information from the surveillance system will ultimately enable these agencies to develop real-time situational awareness regarding the presence, position, movement, classification, activities, intentions and threat levels of entities of interest in their areas of responsibility.

In parallel with conceptualising and developing technological solutions to a large number of technical issues, researchers are working with potential users to determine and analyse their detailed requirements for this type of system in order to fine-tune the solution for maximum impact.

Further impact may be achieved through support by the AwareNet S&T capability for the development of persistent area surveillance products by the South African aerospace and defence-related industry. This application of the capability may lead to the establishment of a cluster of organisations and a family of niche products that could eventually contribute to South Africa's international competitiveness.

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Proudly homegrown radar technology

by Pieter Goosen

South Africa's new Valour class frigates are equipped with powerful target trackers that were produced by local industry based on tracking radar technology developed at the CSIR. They are capable of tracking small targets at long ranges in all weather conditions and form part of the ship's main weapon and air defence systems.

Radar is a kind of remote sensor that uses radio waves to detect, determine the direction, distance and speed of objects such as aircraft, ships, terrain or rain, and map them. A transmitter emits radio waves, which are reflected by the target and detected by a receiver, typically in the same location as the transmitter. Although the radio signal returned is usually very weak, radio signals can be amplified easily. Radar can thus detect objects at ranges where other reflections, such as sound or visible light, would be too weak to detect them. Modern digital signal and data processors allow information to be extracted from these reflections, enabling not only the detection of targets, but also the sensing of information regarding their positions, movement, classification and identification.

The term "radar" was coined in 1941 as an acronym for "radio detection and ranging". This acronym, of American origin, replaced the previously used British abbreviation RDF (radio direction finding). The functions and roles of radar include target search and detection, target tracking and measurements, reconnaissance and surveillance, air traffic control and navigation, space and range instrumentation and weather sensing radar systems.

A radar competence was established in the CSIR in 1945 as part of the World War II effort and has since grown to address South Africa's national needs. The CSIR supports the Department of Defence and the South African aerospace industry with R&D and knowledge application services in radar, electronic warfare sensors and sensor countermeasures.

South African radar innovation

The South African Navy's new frigates are considered to be among the most advanced ships of their kind internationally. The sensors are the eyes of the ship and the radar technology on board is world-class. By developing the tracking radars in South Africa, R350 million was kept in the country and provided the local scientific and engineering community with R&D opportunities. This enabled scientists and engineers to apply and grow their knowledge through real-world experiences in developing and optimising a radar for uniquely South African conditions and applications.

R&D opportunities are not limited to the delivery of systems; the world-class national capability in radar (consisiting of people, know-how and facilities) is being used to continuously adapt systems to the changing scenarios and missions of the South African armed forces. This is made possible through the programmable nature of the radar. The key functions of the radar are implemented in real-time software deployed on custom-developed, high-performance digital computing frameworks. The rapid advances in digital technology can be utilised and continuously incorporated into the systems, while more advanced functions can be developed and integrated locally in the form of new software modules. New and better functionality is constantly researched and developed utilising the MecORT and Test Target Generation (TTG) facilities on the CSIR site in Pretoria. This technology is transferred to Reutech Radar Systems, who will upgrade the operational systems.

Modelling and simulation environments are used during the conceptualisation, design and testing phases of a radar. During development, high-fidelity hardware-in-the-loop simulation environments are used to validate and qualify the operation of hardware and software. The Enigma radar target and countermeasure simulator is such a facility. Enigma stimulates the radar with radio frequency signals that resemble the operational environment. It uses digital radio frequency memory technology developed by the CSIR to digitise, store, delay and modulate received radar pulses that mimic actual reflections and emisions from targets such as aircraft, missiles or ships. This technology is world renowned and will soon be manufactured under licence in the USA.

Field measurements of the radar's operational environment and objects of interest allow the CSIR to continuously improve the performance and functionality of radars to recognise, for instance, an aircraft or a ship. The Fynmeet mobile measurement facility, developed at the CSIR, can measure such characteristics under operational conditions. Derivatives of Fynmeet have been procured by a number of international research institutes.

Sensing the future

The knowledge and years of experience in tracking radar are also being applied in support of the acquisition programme of South Africa's new frontline fighter, the Gripen. The CSIR supported the South African Air Force in pre-studies, requirement definitions, specifications and evaluations of the fighter's multi-function radar. During the Gripen's life-time, the CSIR will play a key role in optimising the application of the radars and self-protection systems and improving their capabilities. Through interactions with the supplier, SAAB Microwave Systems (previously Ericsson), the quality of the CSIR's capabilities was recognised and agreement was reached to work towards close collaboration on future radar-related R&D.

Radar and electronic warfare engineers at the CSIR are currently expanding their research interests to include persistent area surveillance sensors for watching over our national borders and to increase the effectiveness of our security forces.

The continued national investment into radar R&D and innovation enables a growing number of scientific and technological breakthroughs and creates industrial opportunities, placing the CSIR and South Africa at the forefront of new radar sensing capabilities.

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The Enigma radar target and electronic attack simulator developed by the CSIR is used by several international research and development organisations for radar research, development, testing, evaluation and operator training

Below and right: The MecORT and Test Target Generator (integrated on the telecommunications tower) on the CSIR site are used for research into multipath propagation effects and electronic protection

A South African Navy (SAN) frigate fitted with the optronics and radar tracker manufactured by Reutech Radar Systems (Image by AB MJ Pietbooi, SAN)

Dr Bennie Broughton on board a Cheetah fighter aircraft during flight testing

Predicting aircraft flight dynamics

By Dr Bennie Broughton

The prediction and analysis of air vehicle flight dynamics, as well as the evaluation of the flying qualities of new aircraft is a specialist service rendered by the CSIR to the South African Air Force (SAAF). The science of aerodynamics deals with the flow of air around aircraft and the resulting forces and moments, while flight dynamics concentrate on the aircraft's response to those forces. Flight dynamics therefore include the orientation and motion of an aircraft or other flight vehicle, as well as the stability and control of that vehicle.

Closely related to the science of flight dynamics is an aircraft's flying or handling qualities. One definition of flying qualities states they are "those characteristics of an aircraft that govern the ease, precision and safety with which a pilot is able to perform the required mission."

Flying qualities often include many parameters that are very difficult to quantify, such as qualitative pilot ratings of the aircraft handling or ride quality, and various measures to determine the safety of the aircraft from a handling point of view throughout the flight envelope. Modern fly-by-wire fighter aircraft, such as the new Gripen aircraft being accepted into the SAAF, use computers that have full control over the aircraft. Pilot commands are interpreted by the computers, which in turn decide on the correct deflections of the control surfaces to give the aircraft the desired response.

Due to the very high manoeuvrability and performance of these aircraft and the complexity of the control systems, new difficulties arise, which are either not encountered or of lesser importance for conventional aircraft. For example, a dynamic interaction between the control system, the pilots (who are themselves a complex control system) and the dynamics of the vehicle itself can lead to a phenomenon called pilot induced oscillations (PIO) – a dangerous motion of the aircraft that is difficult to arrest.

PIO tends to occur during the most dangerous and demanding phases of flight when precision of control would normally be of the utmost importance. Several aircraft with fly-by-wire control systems were lost during their early development test flights due to PIO occurences. To prevent future occurrences of a handling quality issue – such as a PIO – that can negatively impact on safety, it is often necessary to reduce the performance of the aircraft. In order to find the optimum balance between performance and safety, in-depth knowledge is required of flight dynamics, human factors and an understanding of what happens in the cockpit of the aircraft during the different flight phases and missions.

Before the SAAF's new Gripens can be handed over to the squadrons for operational use, it is necessary to evaluate all aspects of the aircraft's flying qualities. Although Gripens have been used by the Swedish Air Force for many years, the operational tactics employed by the SAAF and the environment in which the aircraft will operate in South Africa differ from those experienced in Sweden. It is therefore necessary to identify any safety or performance issues before accepting the aircraft into operational use. The CSIR is closely involved in the flying qualities component of the Gripen release to service process.

The author, Dr Bennie Broughton of the CSIR, has worked closely with Gripen test pilots to develop a custom reference flying quality specification for the Gripen. Although an excellent academic understanding of the issues is a minimum requirement for the work, it was also necessary to experience some of the practical issues relating to flying qualities and flight testing. As part of his preparation, Broughton therefore also attended the SAAF Operational Test and Evaluation course in the Western Cape earlier in 2006 where he was exposed to actual flight testing in a Cheetah fighter aircraft.

The current flying qualities work on the Gripen is expected to continue after the release to service process is complete. Each future update to the flight control system software of the aircraft by SAAB will have some effect on the aircraft's performance and flying qualities. It will therefore be necessary to evaluate it continually and track changes to the software. Issues unique to South African conditions may also become apparent only after operational testing and evaluation and actual in-service use. Communicating these issues to the original equipment manufacturer requires an in-depth knowledge of the system itself and the associated flight dynamics theory. It is expected that the CSIR will continue to be involved in this process throughout the service life of the aircraft.

The flight dynamics work at the CSIR comprises not only the prediction of flight dynamics of manned aircraft, but also of other air vehicles such as missiles, guided and unguided munitions and unmanned aerial vehicles (UAV). The predicted stability and control derivatives are used to design control systems for the vehicles or to predict the exact motion of the vehicle through air. Wind-tunnel and computational predictions can be used to test whether the release of a store from an aircraft will be safe.

Current CSIR research is aimed at the development of a mini UAV that will be used to evaluate the effectiveness of drag reduction on tailless configurations through reduced aerodynamic stability. To make this unstable, unmanned aircraft controllable, a complex control system is being developed and implemented in collaboration with the University of Stellenbosch. The successful implementation of this control system is highly dependent on accurate prediction of the vehicle's flight dynamics.

Shosholoza (images supplied by MCG)

Optimising aerofoils for best performance

The cross-sectional shape of a wing has a surprisingly large influence on an aircraft's aerodynamic performance and efficiency. Intuition may suggest that thinner wings should produce less drag than thick wings. However, the dependency of a wing's aerodynamic efficiency on the exact shape of the cross section is much more complicated than just the overall thickness of the wing.

Before the Wright brothers built the first powered aircraft in 1903, they performed some of the world's first wind-tunnel testing on different wing cross-sectional shapes, known as aerofoils. Since their early work, thousands of different aerofoils have been designed in an attempt to produce the best for various types of aircraft. Traditionally, engineers would select an aerofoil shape for a wing from a "catalogue" of standard tested aerofoils with characteristics closest to those required for the application in question.

As aircraft designs became more refined and optimised for specific roles, it became clear that one has to design a custom aerofoil for each specific application to get the best performance possible from a wing. In the past, many aerodynamicists saw aerofoil design as a "black art", best left to a small number of peers who specialise only in aerofoil design. However, modern computer technology and computational methods have made analysis and design of aerofoils much easier and more efficient. Where design was often done on a trial-and-error basis, it is now possible to design aerofoils using so-called inverse methods combined with numerical optimisation.

The computational aerodynamics research group at the CSIR has the skills and facilities to design custom aerofoils for various uses, whether for manned aircraft, unmanned aerial vehicles or sometimes even wings that "fly" under water. A recent application was to design the keel and rudder aerofoils for the South African entry to the prestigious 2007 America's Cup Yacht Race, Shosholoza. This design had particularly complex requirements, since the yacht keel is required to function through a very wide range of operating conditions – from reversed flow during the start of a race to much higher speeds where the keel is required to generate side loads of several tons. To design an optimum aerofoil for such a wide range of operating conditions may seem like an almost impossible task, but through the use of inverse design and mathematical optimisation, it was possible to use a computer program for generating and testing thousands of different shapes until one was found with the minimum amount of drag for each of the operating conditions as well as for a series of trim tab deflections.

Currently, the CSIR is developing new methods for designing and optimising two-dimensional aerofoil sections, as well as complex three-dimensional geometries. An example of one new method is a computer program able to design and optimise simultaneously both the wing planform shape and the cross-sectional shapes to produce the most efficient wing for a specific application.

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Research in support of flutter-free aircraft

By Louw van Zyl

Flutter is a potentially catastrophic, self-sustained oscillation of an aircraft in flight. Energy is transferred from the kinetic energy of the aircraft to vibration energy through the interaction of elastic, inertia and aerodynamic forces. Once the flutter speed is exceeded, the smallest vibration induced by turbulence, control inputs or engine vibrations will grow exponentially until some non-linear effect alters the conditions necessary for the transfer of energy, or the structure fails.

All new aircraft types must undergo a flutter clearance to ensure that it will not encounter flutter within its intended operating envelope. Military aircraft may be required to carry external stores that were not envisaged or did not exist when the aircraft was initially cleared for flutter. A flutter clearance must therefore be undertaken for each new external stores combination that the aircraft is required to carry.

The CSIR has been providing a flutter clearance service to the South African Air Force (SAAF) since 1978; more than 100 flutter clearances have been completed successfully. The CSIR is responsible for ground vibration testing, flutter analysis and flutter flight test data analysis. In recent years, the CSIR has also supported the local aeronautical industry with a full flutter clearance service. Aircraft cleared include the Ravin 4-seat touring aircraft and the Slick 360 aerobatic aircraft. In addition, flutter flight testing was conducted for the Diamond aircraft company in Austria and Grob Aerospace in Germany.

The CSIR is not only a specialist service provider, but also develops its own systems and software. A major recent project was the development of a novel ground vibration testing system. The data processing algorithms and user interface developed at the CSIR are aimed specifically at sine-dwell testing of aircraft structures. In this method, the aircraft – with its external stores attached – is excited to vibrate in each of its natural modes in turn. This requires precise frequency control, force control and the correct balance of forces. Dr Becker van Niekerk from Parsec Aero proposed using the CAN-bus architecture for the hardware implementation and also supplied the hardware for the system. The CSIR's Erik Wegman was largely responsible for bringing the ideas and hardware together, resulting in a very capable, low-cost ground vibration test system.

The CSIR also developed systems for exciting the structural modes of an aircraft in flight for flutter flight testing, with separate systems for military and civilian applications. The flutter flight test data analysis software was developed over a number of years, mostly by CSIR researcher Stephan Viviers. Its strengths are fast turn-around and reliability under noisy conditions. The CSIR flutter analysis software includes unsteady subsonic, transonic and supersonic aerodynamic codes.

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CSIR moves into civil aviation research

by Bridget Ssamula

The CSIR has embarked on an initiative to build research capabilities in the civil aviation industry, with specific emphasis on the African continent. Skills and capacity developed in this much-neglected area of air transport are expected to contribute significantly towards improving the industry's safety record and realising its potential as a catalyst for growth, both in South Africa and on the broader African continent.

Civil aviation represents one of the two major categories of flying, encompassing all non-military aviation, both private and commercial. Under the Geneva Convention of 1944, the aviation industry is one of the most regulated industries world-wide, with the International Civil Aviation Organisation (ICAO) acting as the industry's governing body.

The aviation industry research to be undertaken by the CSIR encompasses institutional, technical and operational aspects.

Challenges and strategic research needs

The institutional aspect of aviation encompasses the bodies and institutions set up to ensure the regulatory compliance and alignment of each of the organs involved in the aviation industry. Institutions involved in this work include civil aviation industries at country level and regional organs such as the African Union, the New Partnership for Africa's Development and regional economic communities, such as the Southern African Development Community.

Research in this area is aimed at identifying the setbacks and bottle-necks that are hindering the liberalisation of African skies, and addressing the issues that are holding back the globalisation of the region.

The technical component of the aviation research agenda focuses mainly on the safety aspects of the industry. Safety in the African skies is a critical issue, with Africa's rate of air accidents more than six times higher than the world average, despite the fact that the continent carries only 4,5% of the world's air traffic.

The evaluation criteria for the blacklisting process currently in place with the ICAO and the European Union are detrimental to the already struggling industry. The strategic needs in this research area will focus on setting up regional agencies and harmonising regulations, safety management systems and evaluation criteria to ensure compliance with ICAO standards and the International Air Transport Association's operational safety audits.

The operational aspects of the aviation industry are of vital importance, since the industry is characterised by high capital costs, low profit margins, high competition and, more recently, higher fuel costs and stringent safety and security systems. The aviation industry in Africa is crippled by, among others, shortage of financing, the use of obsolete aircraft, insufficient skills and mismanagement.

Research in this area aims to establish best practice in the aviation industry by learning from countries, regions and airlines running profitable operations. In addition, independent strategies need to be developed particularly for the unique African scenario, with its sparse, inelastic passenger demand and high air travel costs. Tools such as logistics and operational research and modelling can provide cost-effective route and network analysis options, based on transport engineering principles.

The ground-breaking research described above ties in with the CSIR's key objectives of building research capabilities and transforming human capital.

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Bridget Ssamula's research involvement in aviation started with the development of a cost model to run an airline service along a route in a cost-effective manner, to meet existing passenger demand and allow for appropriate aircraft choice for the route. This work was applied to her PhD studies at the University of Pretoria, on the topic "Cost effective strategies to design a hub-and-spoke network for sparse travel demand in Africa". Ssamula also spent time as a visiting researcher at the Institute of Transport Studies at the University of California Berkeley. The aim of her thesis is to develop a hub-and-spoke network design to lower intra-African air travel costs, using logistics and operational research methodologies.

Acumen in advanced aerospace materials expertise

By Philip Haupt and Dr Kamalluddien Parker

Advanced materials are seen as the cornerstone of new and improved aerospace systems and have for many decades been the key driver for the adoption of new aerospace technologies. This is applicable to the design of both airframes and engines.

Recent advances span not only the materials but also related manufacturing technology. New materials, for instance, are tailored according to the desired properties and manufacturability. A good example of this is work in investment casting of nickel-based superalloys for gas turbine engines, where the alloy needs to be tailored for manufacture as well as performance.

Advances and areas of research in the CSIR centre around the following three material types:

- advanced light metals
- advanced composites
- natural/green materials.

Advanced light metals

The CSIR is actively involved in the processing of aluminium, magnesium and titanium for advanced applications in the aerospace, automotive and other high-technology industries.

The CSIR's foundry has been involved in high-technology aerospace castings for the past 18 years and has significant experience in R&D relating to investment casting, process development and optimisation, and component qualification. The foundry's capabilities span art-casting and jewellery-casting to high technology single-crystal (SC) blade-casting. This facility has in the past worked closely with Denel in developing components for the South African Air Force (SAAF) and international players such as Snecma, Turbomeca, Superior Air in the USA, Rolls Royce in Germany and the United Kingdom. The facility has also developed capabilities for SC casting technology for various engines, including the Russian RD33 and the Mig 29 fighter aircraft, which have requirements for some of the highest technologies in the casting industry.

One of the projects funded by the Advanced Manufacturing Technology Strategy (AMTS), which is hosted by the CSIR on behalf of the Department of Science and Technology (DST), is to develop advanced metals manufacturing technologies for complex, thin-walled, light-weight components using the investment casting process.

Titanium casting development, in particular, is one of the main focuses of the CSIR's advanced vacuum-casting facility. A technology consortium including universities and industries, both locally and internationally, is involved in the project. The CSIR is also actively involved in titanium high-performance machining studies as part of the AMTS's titanium beneficiation drive.

The AMTS projects are geared towards enhancing the competitiveness of local aerospace and automotive industries through technology advancement, in line with the global trends of lighter and stronger structures and components.

The facility is further involved in the development of semi-solid metal (SSM) processing of aluminium die-casting that currently receives funding from the DST.

The foundry – together with supportive technologies such as process modelling, rapid prototyping and structural analysis – forms part of a supportive technology platform for the Advanced Metals Initiative (AMI). This initiative was launched in collaboration with Mintek and Necsa in 2003. The Light Metals Development Network is a joint initiative between the CSIR, Mintek and Necsa as part of the AMI and is coordinated by the CSIR. The objective is to provide active support for the growth and sustainability of an international downstream South African light metals industry.

The CSIR is an active founder member of the Rapid Product Development Association of South Africa, which looks at novel technologies for use in advanced manufacturing.

Advanced composites

The CSIR has been involved in the development of novel composite material technologies for the aerospace sector for the past 40 years. Current activities deal primarily with smart structures and novel emerging materials.

Smart structure technology focuses on adaptive structures that can change shape in response to their environment and specific operational requirements. The constituent components of the technology include the tailoring of composite laminates and the design of actuators and sensors. One potential application is for aircraft wings without any control surface that geometrically morph on a continuous basis in order to adapt to their environment.

Emerging materials under investigation include nano composites. These materials incorporate nano diameter fibres embedded in a conventional matrix. In the long term, these materials will allow for enhanced performance when compared to the current generation of materials. The underlying technological advantage of nano composites as applied to the aerospace sector, is increased material performance against wear and damage, improved structural strength-to-weight ratios and improved surface finishes. This technology allows manipulation and exploiting of material properties at metallurgical level.

Natural/green materials

Over the past decade, natural fibre-reinforced polymeric composites that substitute glass fibre reinforcement have witnessed compounded growth of about 7% in volume and value. This is attributed to their unique properties.

The potential advantages of weight saving (light material), lower raw material price from natural origin, and thermal recycling, or the ecological advantages of using resources that are renewable, contribute to the popularity of this material. The most important of the natural fibres used in composite materials are flax, hemp, jute, kenaf and sisal, due to their properties, availability and good performance-to-price ratio.

South Africa's resurgence in the global automotive market and the interest of leading players in the aerospace industries for sourcing natural fibre-reinforced composite products and technology from the country, sparked a project on natural fibre-reinforced composites. This project under the AMTS programme will address the research problems and aims to fulfil in the need for technical applications in structural and exterior components.

As one of the top four facilities in the world, the CSIR's natural fibres centre in Port Elizabeth is involved in developing a natural fibre composite material in conjunction with several academic institutions and industry partners. From a product perspective, the objective is to produce a secondary structure that conforms to stringent aerospace and automotive certification requirements for fire, smoke and toxicity. It will also seek to develop fully renewable bio-composite materials in line with the AMTS and scientific technology plans of international aerospace original equipment manufacturers.

Aerospace human capital development

The need to develop skills in the aerospace R&D environment specifically, and in the aerospace sector in general, underpins the CSIR's technology advancement programmes. Human resource management is using the smart partnerships model traditionally applied to technology advancement.
The CSIR engages with various people, through networks established by the AMTS, universities and further education and training initiatives to ensure that students are exposed to the science of aerospace and have opportunities for financial assistance. These efforts aim to provide continuity in the need for specific research skills and the curriculum followed at the institutions. Coupled to this is the programme to continuously develop existing skills in the CSIR through post-graduate study. The CSIR is working with academic institutions by exposing students to the scientific method and allowing access to wind-tunnel test facilities and experimental equipment, such as stereoscopic particle image velocimetry for quantitative flow diagnostics.

On another level, in collaboration with the AMTS human capital development programme and the Automotive Industry Development Centre, students from universities are placed in an internship programme at various companies over a period of 12 months. The students are exposed to technology challenges and ultimately gain experience in solving industry-specific problems.

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Wind-tunnel balances essential for accurate data

By Peter Bidgood

Introduction

Major strides towards man's first powered flight were made between 1871, when the first wind tunnel was built and 1903, when the Wright brothers made their first powered flight at Kitty Hawk. These developments were made possible largely by knowledge gained from wind-tunnel testing. Even today, with parallel processing computers making in excess of 15 000 processors available, the use of computer modelling is still limited, particularly in modelling of phenomena that occur during the change from subsonic to supersonic speeds (i.e. in the speed ranges where one changes from slower than the speed of sound to faster than the speed of sound). At these speed ranges, a fuzzy region exists where parts of the flight vehicle may experience subsonic and other parts experience supersonic conditions. This is referred to as the transonic region and is the primary test area for which the medium-speed wind tunnel at the CSIR was built.

Function of wind-tunnel balances

The primary aim of a wind-tunnel test is to obtain the loads imposed on a flight vehicle under varying environmental conditions. Thereafter, the science of scale modelling takes over. Using the load data obtained from an accurately scaled model in the wind tunnel, it is possible to predict the flight characteristics of the actual, full-scale aircraft.

The wind-tunnel balance provides that data to an exacting level of accuracy in the presence of large environmental changes, such as temperature. In a fiercely competitive environment, wind tunnels are largely characterised by the quality of data they are able to produce. It is not surprising that the balances developed and maintained at any specific wind tunnel are often referred to as the "crown jewels" and are kept under lock and key, as this is often the underlying technology base.

How they work

Internal wind-tunnel balances are, in essence, lumps of material that have been shaped to produce measurable stresses at specific points under specific loading conditions, and no stress under any other load conditions. The stress levels at these points are usually measured by means of strain gauges, which measure the local material deformation. This deformation (or electrical output from the strain gauges) is mapped to the applied load (calibration) so that when in use, the load can be determined indirectly from the electrical output of the strain gauges. The wind-tunnel model is mounted on such a device to determine any loads on the model. These balances are usually mounted inside the model and therefore referred to as internal balances.

The primary challenge in the production of these devices arises from the fact that they have to measure six load components simultaneously and accurately. In addition to this, two of these loads are

HARM1, the latest balance produced by the CSIR usually very small in comparison to the remaining four. To maintain the required high levels of accuracy, the load components are machined from single pieces of maraging steel. The resulting design is usually not unlike a Chinese puzzle. This creates a challenge for the designer, the stress analyst and the manufacturer. The designs usually require substantial machining by means of spark erosion, whereby the material is slowly eaten away by an electrical spark. This is a slow process; it is not uncommon for the manufacture of a balance to take 12 months to complete. A high degree of confidence in the final design is required, which is ensured, where possible, by finite element analysis modelling. In the case of balances, this is not a simple process, particularly if thermal modelling is included.

Creating a common reference

The escalating needs of the aeronautics community in the mid-90s led to the American Institute for Astronautics and Aeronautics recognising the need for improving the performance of balances. Standards had to be created so that balances from all the USA tunnels could be compared, thus having a common reference from which to advance.

Collaborators in this effort included:
- National Aeronautics and Space Administration (NASA)Ames
- NASA Langley
- NASA Lewis
- Northrop Grumman
- Micro Craft Technology (formally Allied Aerospace)
- Lockheed Martin
- Institute for Aerospace Research
- Veridian (formally Calspan)
- Boeing
- AEDC.

Since then, there has been a significant advance in balance technology. The European community soon followed the USA example and set about identifying key technologies that would be required to obtain any significant advantage. The danger of this was a potentially widening technology gap between the South African and international wind tunnels.

Latest CSIR technologies

Recognising the trend in balance technology, the CSIR's medium-speed wind tunnel team set about characterising its balances and benchmarking them against data quoted from all available sources. A process of research and development and the building of several balances – all of which break with currently accepted design philosophies – have brought the wind tunnels to a point where they can offer several cutting-edge balance technologies.

The latest balance produced by the CSIR's medium-speed wind tunnel, called the HARMS1, contains all the technologies predicted to be relevant by a panel of internationally recognised experts from both Europe and the USA in 1997, as well as some additional technologies.

The future

The process of research, it is said, has a strong tendency to create more questions than answers. This is undoubtedly true for the research done over the past decade on internal balances. Numerous avenues for continued development have opened up as a result of work done thus far. These include a collaborative research effort between the CSIR and the University of Johannesburg, aimed at the development of fibre-optic balances. CSIR research into better sensors, design of experiment and response surface methods, materials (including composites), electronics, data acquisition systems and automatic calibration, as well as fully automated thermal calibration techniques, continues in a successful attempt to keep pace with international standards.

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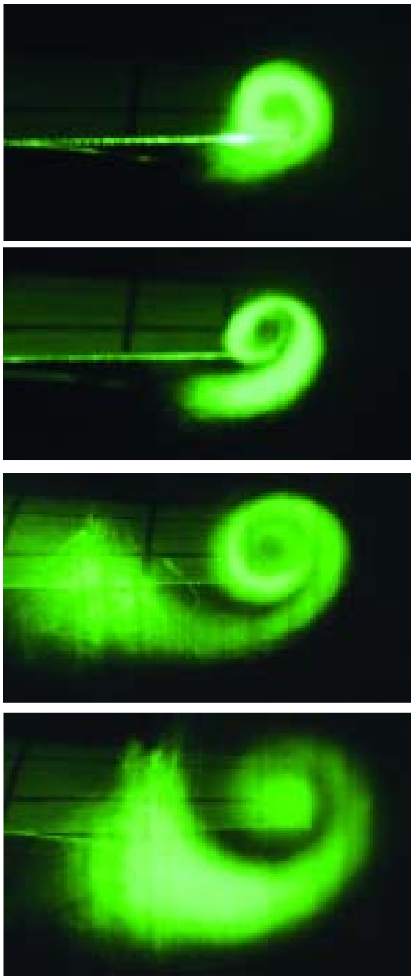
Peter Bidgood

Top facilities and equipment give a competitive edge

By Dr Motodi Maserumule and Glen Snedden

In addition to the wind-tunnel equipment, the CSIR also has an extensive computational fluid dynamics capability that extends into solving industrial flow problems. The capability is powered by a small cluster of computers and has been used to do ground-breaking work on the modelling of store release and unsteady helicopter flows used to optimise the self-protection suite of the Rooivalk Attack Helicopter

Dr Motodi Maserumule



The recent addition of particle image velocimetry equipment allows for qualitative laser sheet images such as this to become quantitative results

THE CSIR boasts the largest and best-equipped wind-tunnel complex on the continent. Seven wind tunnels and a water tunnel, varying from the large 7m low-speed wind tunnel to the smaller high-speed wind tunnel, offer a test and evaluation capability up to 4,5 times the speed of sound. These facilities are backed by world-class instrumentation and measurement capabilities and a team of experts with experience that includes not only local aeronautical achievements relating to the Rooivalk, Umkhonto missile and ACE trainer, but also international experience on Eurofighter and Aermacchi.

The in-house design of internal balances is one of the capabilities that makes the CSIR's wind tunnels uniquely competitive. Internal balances are used to obtain the loads imposed on the flight vehicle during wind-tunnel testing, making it possible to predict the flight characteristics of the full-scale aircraft. The challenge is to produce an instrument capable of absorbing the enormous stresses placed on a wind-tunnel model in one axis while taking precise, high-resolution measurements of all six load components (some of which are very small), and at the same time make them temperature independent.

These wind tunnels form an important foundation for computational fluid dynamics. The CSIR's computational aerodynamics research group focuses on the prediction and analysis of internal and external aerodynamics in different flight regimes with numerical solution of the governing equations of fluid motion. In coming years, the group plans to be a hub of expertise for computational aero-dynamics in South Africa.

The Capital Renewal Programme, funded by the Department of Science and Technology, is making a significant contribution to maintaining the high standard of equipment and facilities.

To date, the following capital renewal projects have been completed:

- A new 1700cfm screw compressor for the Mach 4,5 high-speed wind tunnel, which doubled its productivity
- A high angle of attack (60°) and roll scan capability high-speed wind tunnel, enabling the testing of new generation agile missiles
- A vibration monitoring system for the vital machinery of the premier transonic wind tunnel that helps to avoid expensive failures and plan maintenance activities
- The refurbishment of a turbine test rig
- An internal strain gauge balance repair, gauging and development laboratory to help maintain the development of world-class balances
- An electronic pressure scanning system, with sufficient portability to be used in all of the tunnels, which significantly enhances the pressure measurement capability of the tunnel suite.

Strong links with the South African Air Force (SAAF) through the Test Flight and Development Centre has seen the CSIR develop the capability to support the flutter flight clearance envelope and store configurations of all the SAAF's supersonic fighter aircraft via unique ground vibration test equipment, flight clearance software and flutter excitation hardware.

Rhulani Mathebule and Glen Snedden with the low-cost turbine research facility that has reaped instant reward in securing a place in a European Union Framework 6 aerospace project called VITAL

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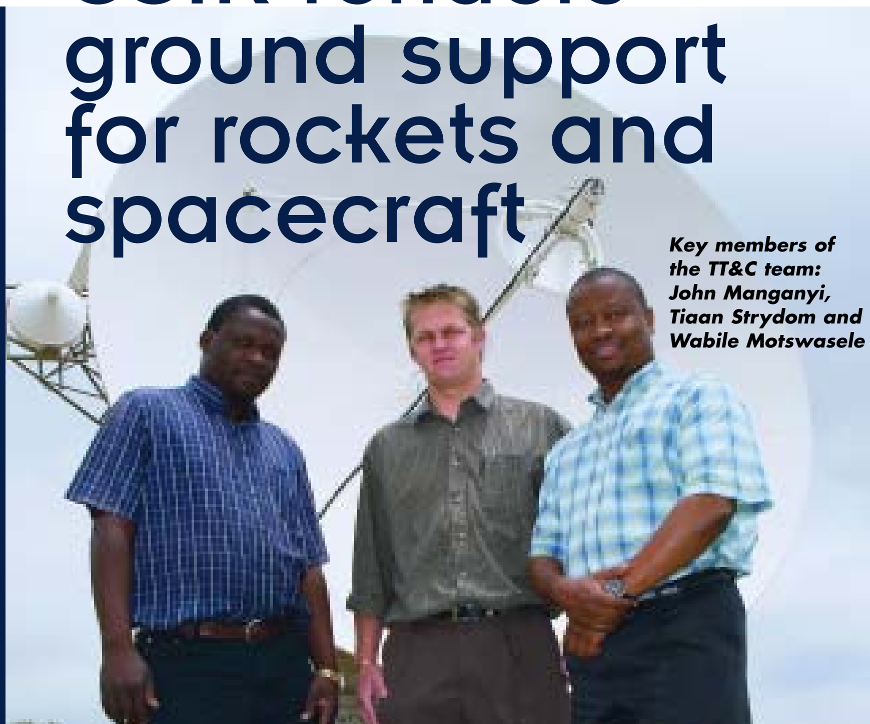
CSIR renders ground support for rockets and spacecraft



Key members of the TT&C team: John Manganyi, Tiaan Strydom and Wabile Motswasele

By Wabile Motswasele

TT&C, a commonly used acronym in the aerospace industry, stands for telemetry, tracking and commanding. In the context of the operations of the CSIR Satellite Applications Centre, this includes support to rocket launches, spacecraft launches and spacecraft operations. The CSIR renders a wide range of TT&C services to a diverse customer base located primarily in the USA and Europe. The centre operates and maintains a number of antenna systems, each optimally designed and adapted for specific TT&C service offerings. Thus each antenna can be considered a product with specific features to support specific customer requirements. With the same infrastructure, the centre also provides satellite tracking and data acquisition services. These services are geared for receiving satellite imagery from a wide but select range of remote sensing satellites orbiting in space.

Tracking involves the capability of a ground-based antenna to locate accurately, lock and track a spacecraft as it orbits in space.

Telemetry refers to the activity of receiving data from a spacecraft. The data are processed by complex ground-based systems for the distinct purpose of displaying spacecraft operating conditions on screen and terminals.

Commanding relates to transmitting data from ground-based antennas to the space craft.

The primary technology base for TT&C systems is rather similar to satellite telecommunications services. A useful analogy would be to consider TT&C service provisioning as the back-office operations and satellite telecommunications service provisioning as the front-office.

The outdoor antenna infrastructure includes the parabolic reflector, the antenna drive systems and the electronics subsystems. The indoor equipment consists of the processing and operations systems. The interface cables between the indoor and outdoor are a crucial component of the architecture. With recent advances in optical fibre technology, links made of optical fibre present major advantages over coaxial-based cables. Improved efficiencies are achieved in terms of signal-to-loss ratio and minimised damage as a result of lightning strikes.

The CSIR's service offerings involve the following in terms of support for a rocket or spacecraft:

- Low earth orbit phase
- Transfer orbit phase
- In-orbit testing
- Life cycle support
- Emergency support.

These services are executed with a comprehensive antenna product portfolio ranging in a wide selection of radio frequency (RF) bands as set out in the table.

The Ka band antenna used for TT&C services. South Africa is one of two countries in the world that operate a TT&C Ka band antenna. Ka band technology is very complex due to the high frequencies, short wavelength and rather narrow beams

Available TT&C frequency bands

RF BAND	FREQUENCY RANGE
L	1-2 GHz
S	2-4 GHz
C	4-8 GHz
X	8-12 GHz
Ku	12-18 GHz
Ka	26-40 GHz

The significance of such a wide RF band is that, considering South Africa's strategic geographical location, it allows the CSIR flexibility in accommodating ever-increasing complex sets of user requirements from a wide range of existing and potential clients.

Less apparent is the fact that TT&C services are – by virtue of the requirement to transmit signals from ground to space – subject to the telecommunications regulatory framework. Therefore, each TT&C capable antenna at the CSIR is licensed by the Independent Communications Authority of South Africa for permission to transmit RF signals. This process ensures that the CSIR can perform its TT&C services reliably without interference from other users.

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Lee Annamalai

CSIR imaging expertise propels SA to a science high

By Dr Bob Scholes and Lee Annamalai

The first "made in South Africa" satellite, called SunSat, was designed and assembled at the University of Stellenbosch and launched by NASA in 1999. The main instrument it carried was a four-band visible and near-infrared high-resolution imager designed and built by the electro-optics group of the CSIR. The innovative optical design of the imager centred on sensor elements attached directly to the surfaces of a cubic prism, thus making the assembly extremely robust to the vibrations associated with satellite launch. When Sumbandila, the next South African satellite, is launched next year, it will carry a Multi-Sensor Microsatellite Imager. This article looks at developments to date.

Following the SunSat launch, the University of Stellenbosch formed a company called SunSpace to nurture and exploit the skills that had been developed during the SunSat project. SunSpace has since manufactured entire satellites and subsystems for various international clients, with the CSIR providing optical design, test and evaluation support in most of these projects. One of SunSpace's early sales was a SunSat-type imager, also built at the CSIR, which was carried on board a Korean microsatellite, KITSAT.

The next step in the development of a South African satellite programme was a three-year Innovation Fund project called the Multi-Sensor Microsatellite Imager (MSMI), which began in July 2003. Its objective was to design, build and bench-test an imager for use in a series of low-earth orbit earth observation microsatellites. A microsatellite has a mass less than 500 kg (about 150 kg is more typical). These small satellites are much cheaper to build and launch compared to the one-to-10 tonne space platforms – the current workhorses of earth observation. As a result, many more can be built, providing operational redundancy and economies of scale. The sensor therefore needed to be light, compact and multipurpose.

The CSIR is part of the MSMI consortium. It provided one of the initial optical designs (not the one that was finally chosen), developed the specifications for the image products, and developed a test application for the data which the MSMI will provide. The CSIR's optronic sensor systems group played an advisory role to the project team on design reviews and the precision electro-optical test, while the evaluation laboratory performed the test and evaluation of the imager to ensure conformance to specifications. The test and evaluation laboratory performed vignetting and flat-field tests on the imager, while radiometric calibration was a responsibility shared between the optronics sensor systems group and the CSIR National Metrology Laboratory. These tests ensure that the optical telescope and detector are performing at the optimum in order to capture the best data when the satellite is in orbit.

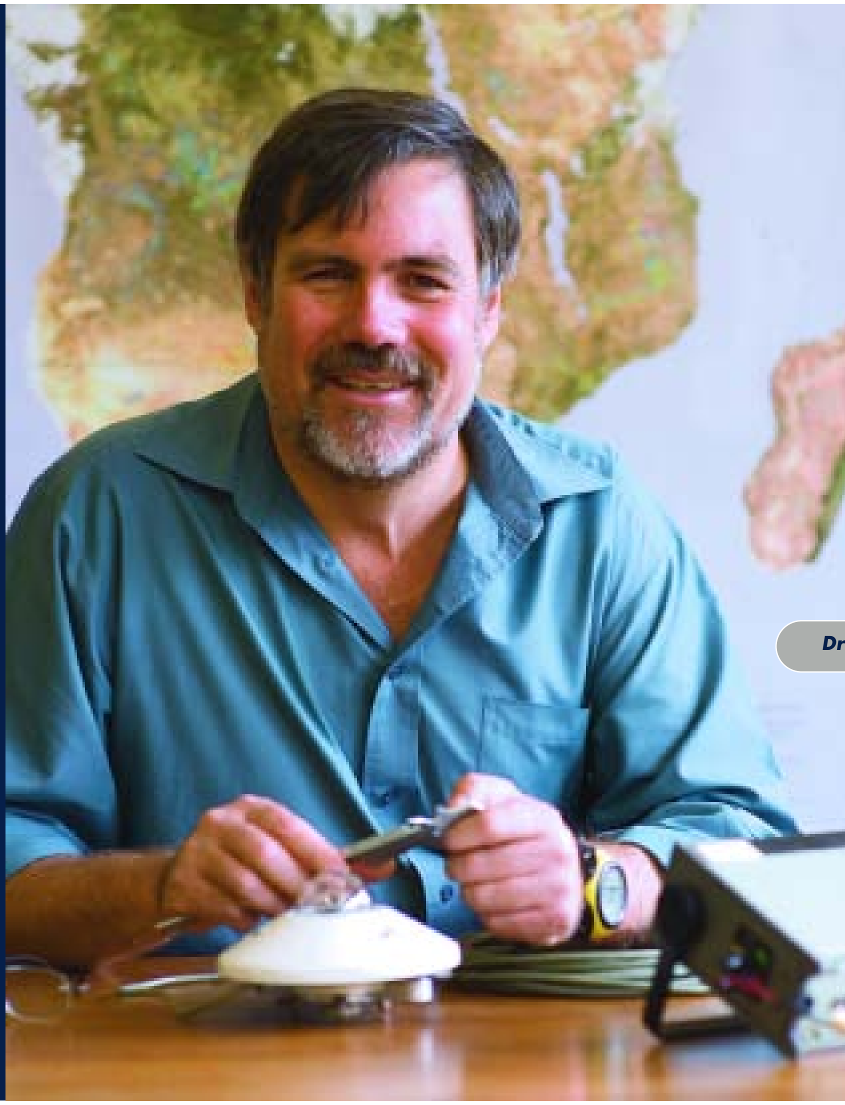
The MSMI family is quite unusual in that several sensors share the same focal plane, and thus all look at the earth through the same telescope. This saves on weight and provides the power and versatility of having information from several different types of sensors, while avoiding the problems of aligning and coordinating images taken from different telescopes or satellites.

The principal sensor is a high-resolution multispectral "pushbroom" device with six user-specified bands in the 400 to 1 000 nm wavelength range, which covers the visible and near-infrared region. The linear sensor elements can cover a path (a "swathe") 27,6 km wide with pixels 4,6 m wide. Each is fitted with an individual filter that lets through only a defined set of wavelengths. The CSIR ran a comprehensive process to recommend which bands should be selected for the versions of the MSMI to be carried on the South African satellites (See table below).

Next to the multispectral sensor is a panchromatic (black-and-white) pushbroom sensor with twice the resolution (2,7 m ground sampling distance), a 23,6 km swathe, and an outstanding signal-to-noise ratio. One of its main uses is pixel sharpening, a technique that effectively improves the resolution of the multispectral sensor to the 2,7 m range. In addition there is a second panchromatic sensor:

The bands selected for the MSMI on the first two South African satellites

Band (nm)	Description
BLU 440-510	Blue wavelengths are often left out, because the dust in the atmosphere makes them turbid. That is why it is put in – knowing the amount of aerosols allows the image to be corrected for dust in other wavebands. It is also good for seeing through shallow coastal water and for providing the blue in true colour images.
XAN 520-540	This is an experimental band that coincides with absorption by the secondary photosynthetic pigment xanthophyll. It is hoped that it will provide information about stress in plants.
GRN 520-590	This band provides the green in true colour images. The yellows and greens can be split by subtracting the XAN band from GRN.
RED 620-680	Apart from providing the red in true colour images, this band coincides with the main absorption by chlorophyll. This is a heritage band, widely used on earth observation satellites as part of vegetation indices.
REI 690-730	When plants are under stress, such as from drought, their absorption spectrum shifts in this red edge zone.
NIR 840-890	Green vegetation reflects most of the radiation that falls on them in the near-infrared. Therefore this band provides a good reference band for normalising vegetation indices. It is a heritage band that goes with the red band.



Dr Bob Scholes

two-dimensional with the ability to take snapshots like an ordinary digital camera. It therefore preserves the precise spatial relationships between the image elements, and is intended for use in object identification using pattern recognition. Each snapshot covers a 3,3 x 2 km area in 2,6 m pixels.

The next South African satellite, Sumbandila (which has the serial number ZASat-002), is due for launch in May 2007 aboard a Russian submarine. This will be a pathfinder mission to test the technology – the telescope is slightly smaller than the one to be carried with the normal MSMI package, and the ground sampling distance of the multispectral sensors is therefore 6,5 m (with a swathe of 40 km). The CSIR Satellite Applications Centre, through its tracking, telemetry and command capability, will be responsible for communication with the satellite once it is airborne. The centre will also be responsible for downloading the data Sumbandila will be generating.

It is envisaged that the yet-to-be-named ZASat-003 will be launched a year after ZASat-002's departure into space. It will carry the full MSMI instrument, as well as a hyperspectral imager designed and built by Flemish collaborators. The hyperspectral imager shares the same telescope and has a 14,9 km swathe with 14,5 m ground sampling distance. It slices up the spectrum between 400 and 2 350 nm into 200 bands, each 10 nm wide. It will be used mainly for detecting crop diseases and stresses, as well as for prospecting new mineral deposits.

The CSIR is actively building its research capacity in hyperspectral analysis so as to be able to use this new tool effectively. A key initiative in hyperspectral image processing has been an international collaboration and exchange programme between the CSIR and VITO (the Flemish institute of technology), to use hyperspectral processing to detect alien and invasive vegetation. These competences will be used to support and process data collected from the South African micro-satellites and support the range of activities for which these satellites are envisaged.

The unique capabilities of the MSMI package will be tested to the limit by an application designed in a collaborative effort between the CSIR and the Agricultural Research Council. The application aims to improve the quality of forecasts of food security in Africa.

Famine and droughts affect millions of people in Africa and billions of dollars are spent every year trying to mitigate their effects. The food security application sets out to integrate information to be provided by the MSMI and other satellites on the area planted with crops, the types of crop and their projected yield at harvest, with social and economic data about demand, supply and affordability of food. The aim is to reveal the locations of food shortages, at local government level, several months before they occur and thereby direct the interventions more accurately.

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South Africa to play active role in

A simulation of the various swathes created by the four sensors in the MSMI package that is to be carried on board the ZASat-003

The assembled SunSat (ZASat-001)

South Africa will launch its own low-earth orbiting microsatellite, Sumbandila, abroad a Russian submarine near Murmansk on the Barents Sea. It's the first of a series of national satellite developments that intends giving South Africa more affordable access to space technology and data.

developing Africa's space capabilities

By Dr Bob Scholes, Professor Arnold Schoonwinkel and Hendrik Burger

*Scholes is a systems ecologist at the CSIR,
Schoonwinkel is Dean of Engineering at the University of Stellenbosch
and Burger is project engineer at SunSpace Ltd.*

For a fuller version of this article, see Quest: Science for South Africa (2006), 3(1), pp32-35.

The name Sumbandila, meaning "lead the way" in Tshivenda, was selected as the winner in the "Name the satellite challenge" that was open to all South African school learners in grades 7–12.

Although the country's work on satellites is relatively new, it has been marked by success. In February 1999, a NASA rocket carried SunSat – a microsatellite designed and built at the University of Stellenbosch – into orbit. This pioneer survived in the space environment for nearly two years, beaming back images of the earth's surface and testing several innovative aerospace technologies. SunSat is one of a handful of satellites that were designed and built by university students and then launched successfully. And its launch made South Africa one of a small group of nations with the capacity to build and operate space platforms.

Why a space programme for a developing country?

The "space race" has its origins in national pride. Beyond nation-building, how-ever, space programmes have strategic value as well as industrial spin-offs. South Africa, with countries such as China, India and Brazil, belong to a small group of developing nations endeavouring to master technologies required to leapfrog from low-value farming and mining economies to sophisticated service and manufacturing economies that offer higher growth rates and better jobs. These countries already have active space programmes. Two African countries (Algeria and Nigeria) recently purchased satellites from the developed world – South Africa believes that building our own grows our capacity far more effectively.

The task of designing and building satellites, together with the data-processing software and supporting ground stations, raises the competitive standards across the fields of technology and manufacturing. Advanced capacity in materials science, electromechanical design, communications, optics, data-handling, precision manufacture, testing and system integration is required. These high-tech developments have applications in many other spheres. South Africa has already notched up significant sales in the competitive domain of space-related hardware and created a small but competent industrial sector. Most important, a space programme develops, retains and attracts skilled and talented people for the country.

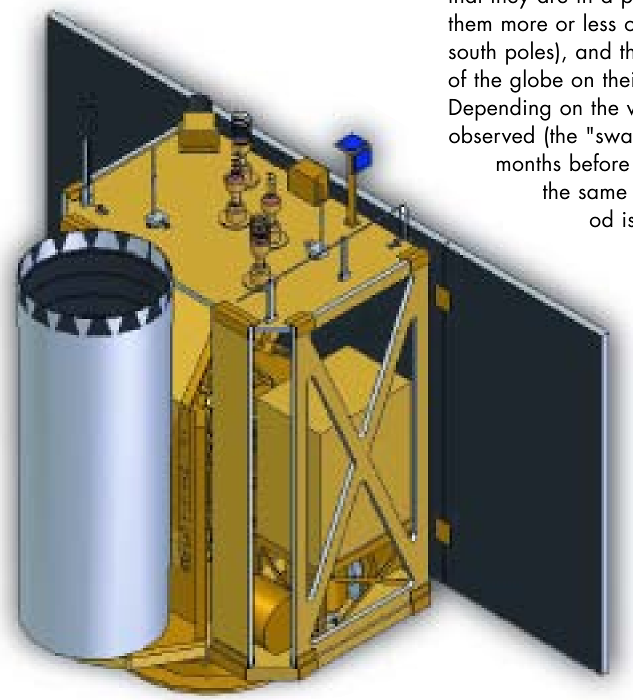
The satellites will provide great earth observation benefits. The Multi-Sensor Microsatellite Imager (MSMI) package to be carried by South Africa's satellites was designed to improve food security in Africa, but meeting the observation specifications for this challenging task also has the potential to achieve much more.

African and donor nations spend over a billion rands a year on hunger alleviation. If the MSMI can be improved, even if only by a few per cent, the reliability of information about who needs what food and when, and the savings on loss of life and resource wastage will easily pay for the cost of the satellite. Many other satellites in space can (and do) help, but none have the unique combination of wavebands and image detail needed to monitor crop development in smallholder fields in Africa. As a scientific bonus, the full MSMI package to be carried on future satellites will include a hyperspectral sensor that slices the visible and infrared spectrum into over 200 narrow bands, providing a unique "spectral signature" for different types of land surface. By measuring the precise absorption bands of particular molecules, hyperspectral sensors can provide information about crop health, nitrogen content, soil type and mineral resources.

Weed control is another example of the way MSMI sensors can be applied. The South African government spends hundreds of millions of rands each year combating water-wasting alien vegetation so as to increase the flow in our rivers. If the MSMI can direct this investment more precisely, the benefits can be greatly improved.

A third example involves urban service delivery. Like most developing countries, South Africa is urbanising rapidly. The MSMI can help to map and classify informal settlements and help direct services to where they are needed.

A computer-aided design image of the ZASat-003 satellite, carrying the full MSMI sensor package



Recipe for a satellite

Decide what you need it for

Designing a satellite involves a series of compromises: decisions need to be based on mass, cost, reliability and various performance characteristics. Sometimes different applications have similar requirements in terms of the wavelengths in which they observe the size of the objects they need to be able to see, and the frequency with which they need to see them – however this is not always the case. So it's crucial to decide, first of all, what the satellite is needed for, and then to work out the design specifications for satisfying those needs.

Select an orbit

"Space" begins about 100 km above the earth. The higher the orbit, the more expensive it is to launch the satellite. But orbits lower than 1 000 km experience a small drag caused by the remnants of the atmosphere. Unless it carries "booster" fuel, the satellite gradually slows down and drops out of orbit.

The higher the orbit, the harder it is to see small objects on the earth's surface. Therefore, earth observing satellites typically occupy low earth orbits (LEO) some 500–900 km up, which means they make one complete circuit around the earth about every 90 minutes. During this time, the earth rotates beneath them (assuming that they are in a polar orbit, which takes them more or less over the north and south poles), and they see a different part of the globe on their next pass. Depending on the width of the strip observed (the "swathe"), it can be days or months before they pass directly over the same scene again. This period is called the revisit interval. In practice, the revisit interval must also take into account the possibility that the scene may be obscured by clouds. Satellites that must stay exactly in one place in the sky have to occupy a very special geostationary orbit. This is an equatorial orbit (going around the middle of the earth rather than over its axis) at approximately 36 000 km above the ground. Since there is only one such orbit, and it's in high demand for telecommunications and weather satellites, the "parking spaces" in the geostationary orbit are strictly regulated.

Select a sensor system

Different features on the earth's surface vary in size and spectral reflectance or radiance. Different sorts of sensor are needed to detect this returning electromagnetic radiation. The visible and near-infrared part of the spectrum can be covered using cheap, robust and sensitive silicon charge-coupled devices (CCDs). The longer wavelengths need more exotic detectors.

Most satellites do not form an image by taking a two-dimensional snapshot like a digital camera. Instead, they use the forward motion of the satellite to scan along the scene using a one-dimensional array of sensors, rather like a scanner. The advantage of microsatellites is that they're relatively easy to point to see something that does not lie directly below the satellite path. The same inertial control system can be used to "nod" the sensor along the path, so that it dwells on a scene for a longer time, thus capturing more light. This feature becomes important if you're looking at tiny objects within a narrow wavelength band.

The type of sensor and the quality of the optics control the resolution (the smallest detail detectable on the focal plane). The telescope focusing on the image, together with the altitude of the orbit, then determines how big an object this becomes when translated into its size on the ground. The swathe width is determined by the number of sensors you can pack across the focal plane. If you want to see small objects on the ground, the swathe needs to be narrow.

Fit the package together

The sensors, optics and systems for control, navigation, data storage, communication and power supply all need to work seamlessly together – and fit into the microsatellite mass and volume restrictions. They have to work flawlessly, despite the violent shaking of the launch and the hostile environment of space. So they need a rigid chassis made of light, strong materials and much careful design and testing.

The prototypes begin as three-dimensional drawings and computer models. Then physical models are built, to exacting standards, with the right mass and shape. The components are baked, irradiated and shaken to the point of failure – first individually, then together – and redesigned if necessary. Then an exact duplicate of the satellite is built and exposed to rigorous tests that mimic launch and space conditions. Once it passes all the tests, the actual satellite is built and packaged for shipping to the launch site.

Design and build the ground sector

A satellite in space is no use if you can't communicate with it or use the data it provides, so a ground sector must be built. The elements that stay behind on earth – the antennas, control systems, data processing hardware and software, image delivery systems and applications developed for the data – are typically as expensive to build as the space hardware itself. Fortunately, South Africa has certain infrastructure in place. This includes the CSIR Satellite Applications Centre that will be responsible for operations, telemetry, tracking, control and data capturing when Sumbandila is launched. Other partners in this Department of Science and Technology-developed project include the University of Stellenbosch, SunSpace and Information Systems. The University of Stellenbosch is responsible for managing the project and training students, while SunSpace and Information Systems are tasked with building the satellite.

The task also includes raising user awareness, training new operators and preparing everyone for the deluge of data when these come.

Satellites come in different sizes

According to broadly-accepted convention, satellites are classified as follows:

>500 kg	satellite (most communication, weather and earth observation satellites)
10–500 kg	microsatellite (includes many of the research satellites in space)
1–10 kg	nanosatellite (currently under development)
>1 kg	picosatellite (no well-known ones yet)

In practice, launch opportunities are defined as much by the volume occupied by the satellite as by its mass. ZASat-003 must fit into a box with dimensions 600x600x800 mm. The solar panels and the telescope baffles unfold once safely in orbit in space

The South African satellite platforms

	ZASat-001 (SunSat)	ZASat-002 (Sumbandila)	ZASat-003
Launch date and place	23 Feb 1999 Vandenberg Air Force Base, California USA	May 2007 Barent Sea, Russia	December 2007 Barent Sea, Russia
Orbit	Oblique eccentric 620–850 km	Polar 500 km	Polar 660 km
Sensors	4 bands in the visible and near infrared 15 m GSD* 52-km swathe	6-band Multispectral 6.5 m GSD* 40-km swathe Panchromatic area	6-band Multispectral Panchromatic pushbroom Panchromatic area 200-band hyperspectral
Total mass	64 kg	60 kg	150 kg
Optics		1,2 m focal length, 200 mm aperture	1,72 m focal length, 280 mm aperture

* GSD (Ground Sampling Distance) gives the approximate minimum size of the objects that can be seen on the ground

A test model of parts of the MSMI telescope

The past two decades of SA's space history

1991–1999 A group of engineering students at the University of Stellenbosch, led by Garth Milne, Arnold Schoonwinkel, Jan du Plessis and Sias Mostert, decided to design a microsatellite as a collective project.

Microsatellites are quicker to design, cheaper to build and launch and more agile in space than conventional satellites weighing several tonnes. SunSat was built on a shoestring budget in the University's Department of Electrical and Electronic Engineering, with optics designed and manufactured by the CSIR. SunSat used off-the-shelf electronic components as far as possible rather than the very expensive custom-made, space-certified hardware typical of the big space agencies; NASA carried SunSat into orbit, along with a satellite of its own.

2001 To maintain the momentum, the University of Stellenbosch created a company called SunSpace to design and manufacture aerospace components. It has supplied satellite components, such as optics, sensors and starfinders and a complete microsatellite, for an international client.

2003 The University of Stellenbosch, SunSpace, the CSIR and the Agricultural Research Council formed a consortium, the Multi-Sensor Microsatellite Imager (MSMI), to build a new imager package for future microsatellites.

2006 The South African Cabinet approved a programme of earth observation satellites – the ZASat series – for launches from 2007. "ZA" is the international designation for South Africa. ZASat-002 (the second South African satellite) is a smaller, lighter technology demonstrator for ZASat-003, which will follow about a year later carrying the full MSMI package. Both launches will take place on a commercial basis from a Russian submarine in the Arctic.

A space agency for South Africa
– a holistic frame of reference

By Dr Jan Roodt

The South African government approved the establishment of a space agency during 2006. Leading up to this, a study of several other agencies in the world highlighted the diverse nature of these organisations even when considering those in smaller countries. This led the Department of Science and Technology (DST) to contract the CSIR for a study to establish the elemental framework of a strategic value proposition and operational directive for a South African space agency.

The key question was to determine the objectives of a space programme. Several imperatives were raised immediately, notably those highlighted in the Accelerated and Shared Growth Initiative for South Africa (AsgiSA[1]), such as the development of human capital and establishment of empowered small businesses. The strategic value proposition for access to space had to address these issues. In doing so, it would direct the activities of the South African Space Agency (SASA) to develop this specific sector of the social, technology and economic infrastructure and take into account the other initiatives, especially the aerospace drive.

To structure and analyse this complex socio-technical system presented several challenges. Many of the pertinent factors cannot be quantified in a meaningful manner, as they link social and political dimensions and technical elements in intricate ways. Several uncertainties are inherently part of this landscape, for example, whether South Africa should develop a launch capabi-lity and what the political and social impact of such a high-cost endeavour would be. Would it be economically viable, or drive the development of specialised skills that would help position South Africa for sustained growth? It was obvious that a "big picture" approach was needed to develop a shared understanding of the problem, which would leverage the power of consensus to define the shape and character of the new agency.

The role of a space agency

Any systematic approach to developing a common understanding must first acknowledge those boundaries or constraints that are beyond manipulation. These realities dictate the possible outcomes. For example, South Africa is a developing country with a specific historical context that forces certain issues to the fore, such as ways to support the efforts to erase the second economy, support for development of a scientific prowess to position the country for global recognition, and the agency's potential to contribute to the realisation of the dream of the State President, Mr Thabo Mbeki, to see Africa develop into a leading force in all aspects of life on a global stage.

Additional issues include the roles of other African countries with similar aspirations and active space initiatives, particularly Algeria and Nigeria. An agency in South Africa will clearly have to manage many facets, ranging from technology and social dimensions to political.

Structuring the problem "space"

CSIR Defence, Peace, Safety and Security has years of experience in dealing with large system-of-system analysis and synthesis studies on behalf of the Department of Defence (DoD) and the Armaments Corporation of South Africa (Armscor). This experience and its strong links with the Swedish Defence Research Agency (FOI), led to the CSIR being called upon to assist with the mammoth task of establishing a framework.

Two stages were proposed to the DST: during the first stage, a non-quantitative analysis and synthesis would be done to develop a consensus-based launch pad for the second stage that would focus on a technology audit and road mapping exercise. It was hoped that this first stage would support the DST, who would probably be the custodian of the agency during the initial formative years, to discover where to focus the attention of phase two. This article deals only with the first stage.

The method proposed by the CSIR

[1] http://www.info.gov.za/asgisa/asgisa.pdf

Dr Jan Roodt

was based on work of Dr Tom Ritchey of the FOI in Stockholm. His work on computer-aided morphological analysis[2] was used successfully in the past by the CSIR to develop similar frameworks for the DoD, such as the frame of reference for the development of a cyberspace protection capability. In view of his extensive experience, Ritchey was contracted as part of the CSIR team to support the DST.

Morphological analysis – discovering the anatomy of the South African space landscape

A small team of knowledgeable individuals was proposed by the DST to participate in a workshop during June 2006 at the CSIR. These people had a good grasp of the dimensions relevant to the proposed effort around space in the South African context. Participants represented the Department of Trade and Industry, the Department of Communication, the DST, the South African Astronomical Observatory and the CSIR.

Morphological analysis (MA) – best described as facilitated creativity amongst the small group of subject matter experts – uses several iterative steps or phases of analysis and synthesis, which form the basis of developing scientific models[3]. A central feature is facilitated group interaction that supports structuring of the complex problem space and development of a common and shared modelling framework. This framework is open to thorough inspection with traceability built into it. Software developed by the FOI and maintained under agreement by the CSIR develops and captures the model versions at every iteration.

Several issues or dimensions were discussed, such as the link between the current aerospace drive, near-space platforms like those proposed for a novel surveillance system called AwareNet (see article in this issue of *ScienceScope*) and the utilisation of satellites. Attention was also given to synchronisation of these efforts for maximum effect; leveraging of existing capabilities in South Africa; leveraging the high regard for South African astronomy globally to enter new "clubs" of knowledge sharing to the benefit of all South Africans and eventually Africans in general. The latter brings to mind the Southern African Large Telescope (SALT) and the work on the newest concepts of radio astronomy by bidding to host or contribute to the Square Kilometre Array (SKA[4]).

The diagram shows a specific configuration of the final MA map as it was delivered to the DST. Six dimensions are shown: each of these "variables" is populated with a number of "states".

For example, the dimension or variable "Current programmes" has the states:
1) SKA
2) Micro satellites
3) ARMC
4) SAEON
5) COMSAT
6) SECURITY
These states are linked to current endeavours in South Africa.

The model may be used to inspect links and synergies. In the case shown (MICRO SATELLITES being selected as the state in the variable CURRENT PROGRAMMES), it is clear that all national imperatives are answered by developing an industry in micro satellites and that space research, frameworks for industrialisation, earth observation and satellite engineering will benefit from such a project. At the same time, it can be seen that certain facilities must exist, like the CSIR Satellite Applications Centre, which are government-owned or controlled facilities. No industries were considered, as it is left to government to decide how to empower industry, given these insights.

The traceable model can be used to discover or understand relationships and is the result of consensus amongst the workshop participants. However, several presentations to stakeholders confirmed that experts covered the important elements adequately. This model may be expanded in future to accommodate new insights (with traceability inherent) and the current thinking, based on current information, is captured for further synthesis and analysis.

What was discovered?

This model has a specific context and can be used only to analyse the environment it was designed for, in this case space-related programmes, facilities, stakehol-ders, etc. When interrogating the model, several interesting observations were made.

It is obvious that the SASA must answer to national imperatives. Through

[2] T Ritchey: *Problem structuring using computer-aided morphological analysis*, published in the Journal of the Operational Research Society during 2006
[3] T Ritchey: Analysis and synthesis – on scientific method based on a study by Bernard Riemann. Syst Res 8(4): 21-41 and revised for online publication at www.swemorph.com/pdf/anaeng-r.pdf
[4] http://www.skatelescope.org/PDF/news/press-release-SKA_site_final_1.pdf

(Why) Objectives (National Imperatives)	(What) Activities/Functions	Current programmes	(Who) Primary stakeholders	Required human capital	Facilities
Poverty alleviation	Astronomy	SKA	Government (departments, municipali-ties)	Highly qualified natural scientists, highly skilled technicians	HartRAO
Economic development/growth	Space research	Micro satellites	Government agencies		HESS
Industrial competitiveness	Earth observation	ARMC	HEIs	Highly qualified engineers	KAROO
Enhanced resource management	SatCom	SAEON	Industry	Complex programme and system management	SALT/SAAO
Enhanced crisis/disaster management capabilities	Satellite engineering	COMSAT	Civil society	Application development	BOYDEN
Enhanced regional cooperation	Framework for industrialisation	SECURITY	NGOs	Smart users	HOUWTEQ
Enhanced regional stability	Military surveillance		Heritage & environment	Innovation specialists and integrators	SENTECH
Space R&D competitiveness	Position, navigation and timing			Entrepreneurs	Transtel
Independence and national prestige	Access to space (Launch)			Regulation and legal specialists	OTB
Enhanced national cooperation				PR and communication skills	CSIR Satellite Applications Centre
				Human interaction skills	Meraka Institute
				Procurement & logistics professionals	HEIs
					HMO
					National Disaster Management Centre

well-designed programmes, it will have to advance the level of science and technology, human resources development, go beyond science and technology and deliver growth in such diverse fields as logistics and legal affairs. It must impact the quality of the lives of the population on several levels, including cultural pride and heritage and open the door to the exclusive clubs of nations with access to space to allow South Africa and Africa to share in the rich diversity of knowledge available to these nations. At the same time, it should open up opportunities for South African industries to carve niches for themselves.

South Africa has a rich heritage in astronomy. It is now obvious that the SKA will be situated either in South Africa or Australia. In any event, the current work on prototypes for the SKA will enable South Africans to contribute to a global pool of knowledge through our system-level engineering and signal processing abilities, as is evident from the technologies that underpin the programmes and functions shown in the map.

The next steps

The strengths of the South African technology base can easily be deduced from this morphological analysis. This must be used during the next phases to develop technology and developmental roadmaps and during audits of existing capabilities. It will allow for risk mitigation and the focused application of scarce resources. Small economies cannot defend large research programmes that do not deliver medium-term social impact. As was argued recently by Mostert and Roodt[5], a science such as astronomy is a good example where social benefit is slow to materialise, but once the benefits of a deeper positioning around cultural knowledge is shown, funding becomes a secondary issue.

South Africa will play a major role in the establishment of the SKA, whether it is built in Africa or Australia. This means that our signal processing knowledge and system engineering ability will grow, which will definitely impact our growth potential positively as we seek to develop large projects in Africa, including development of infrastructure and communication links supported by our space efforts. Collaboration with large suppliers of communication and geo-positioning satellites becomes a possibility: we could now link into the Galileo global positioning system, for example, and work with companies like Alcatel Alenia Space in France, one of the largest suppliers of large satellites in the world, while simultaneously carving a niche in hyper-spectral optical subsystems for these satellites.

The opportunities are endless and the South African spirit of innovation is acknowledged widely. It will be the task of the SASA to develop the landscape through appropriate action within the established holistic framework.

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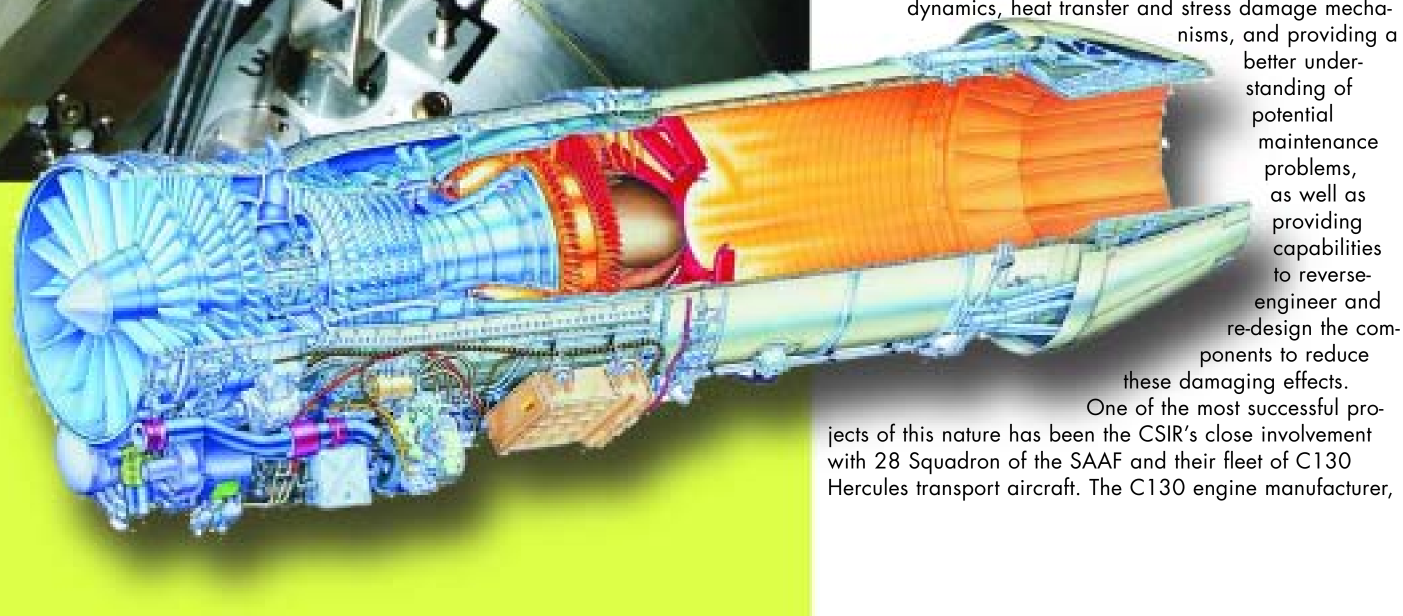
[5] S Mostert and J Roodt: *A remote sensing roadmap for developing countries*, presented at the IAC UN Workshop of Small Satellite Programs for Developing Countries, Valencia, Spain, 2006

CSIR gas turbine technology smartens up future aircraft

By Philip Haupt and Glen Snedden

Glen Snedden



Technology projects ranging from the design of entire engines to the detailed analysis and repair of specific components have been developed at the CSIR in the field of gas turbine technology over the past 25 years. Current research and development (R&D) is driven by international relationships and alliances, whereas most requirements, and hence expertise, were initially driven by the needs of the South African Air Force (SAAF).

The CSIR harnesses skills from across the country through an inclusive network of universities and institutes to develop and retain key gas turbine R&D technologies, particularly for the hot-end – or turbine section – of a gas turbine engine. Hot-end technology is seen as a main enabler in the development and maintenance of gas turbines world-wide and is heavily controlled by the world's leading nations such as the USA. It is therefore testimony to the CSIR's skills and experience that the group has worked with original equipment manufacturers on three continents (Rolls Royce in the USA, Snecma in France and Klimov in Russia) on some of the most important defence projects in South Africa's industrial history.

Currently the CSIR is developing tools, expertise and techniques to be able to support the SAAF in the use and acquisition of new strategic assets, as well as in maintaining its aging fleet. This is achieved via two technology defence projects involving nine institutes and universities, and technology partnerships with original equipment manufacturers such as Volvo Aero in Sweden and Snecma Moteurs.

Current activities

Over the past three years the CSIR has moved towards the smart user/smart buyer philosophy. Nevertheless, the major technological focus is still to minimise the effects of the hot-and-high environment in South Africa, as well as the associated operational environment.

Hot-and-high takeoff conditions prevalent on the South African Highveld result in two damage mechanisms. The overall temperatures in the main gas path in the aircraft engines are elevated by a function of the increased inlet temperature, an effect which can lead to severe component damage, especially to those in the hottest part of the engine. The second, and by far the more significant mechanism since it cannot be eliminated by reducing thrust as is the case for the first mechanism, is the increased temperature and reduced volumetric flow of the coolant air to those same hot components. These include the nozzle guide vane, the first stage rotor blade and their supporting discs.

The CSIR focuses on understanding these aerothermodynamics, heat transfer and stress damage mechanisms, and providing a better understanding of potential maintenance problems, as well as providing capabilities to reverse-engineer and re-design the components to reduce these damaging effects.

One of the most successful projects of this nature has been the CSIR's close involvement with 28 Squadron of the SAAF and their fleet of C130 Hercules transport aircraft. The C130 engine manufacturer, Rolls Royce Corporation, reduced the cycle life of particular hot-end components by over 60% and removed the flight hour limit, which necessitated the SAAF to verify the claims of the manufacturer independently. This led to the CSIR undertaking a detailed reverse engineering, aero-thermodynamic and structural analysis programme of the engine components involved. Once the models and analysis tools were put in place, Rolls Royce Corporation was satisfied with the CSIR's analysis capabilities and the CSIR became full partners in the programme to investigate and solve this problem. Other partners were the National Research Council (NRC) in Canada, the United States Navy, the United States Air Force and the Defence Science and Technology Organisation (DSTO) in Australia.

The CSIR performed computational fluid dynamics and transient stress analyses (both advanced 2D and detailed 3D models) as input to the final component life assessment. The organisation also constructed the high-fidelity mission cycle for all the users and performed the stress analysis of spin pit components and the development of the only CAD model of the T56 in existence today. In addition, the CSIR performed independent life assessment analyses to verify the calculations reported by Rolls Royce Corporation.

While the final result may not be encouraging (the reduced life was unfortunately confirmed), the value of the models and data transferred are immeasurable to the safe and cost-effective operation of the aircraft in future.

Collaboration

The CSIR turbine technology area collaborates with the following entities:

- University of Pretoria
- Stellenbosch University
- University of KwaZulu-Natal
- University of the North
- University of North-West
- University of Cape Town
- Premier ThermoFluids
- SAAF.

Future role

The CSIR gas turbine technology area is putting technology in place to support new and future aircraft acquisitions. While the equipment and levels of technology may change, the basic operational environment has not. The same situation can be envisaged for the future, along with some new difficulties resulting from the increased level of technology inherent in the newer engines being purchased by the South African government. The main challenge is to push the available minds and tools forward two decades as illustrated in the table.

To cope with the leap in technology represented by the new engines currently entering local service, the CSIR is utilising the traditional Department of Defence (DoD) sources of funding, as well as funds from the Departments of Science and Technology (DST) and of Trade and Industry (the dti) and the European Union (EU) to consolidate existing knowledge and facilities. The network with local and international universities and original equipment manufacturers is also being expanded and skilled individuals are increasingly being developed through links with specific international gas turbine companies such as Volvo Aero and Snecma Moteurs.

Recent highlights include:

- The CSIR's aerospace investment foundry has undergone a facility upgrade and is involved in collaborative research with Volvo Aero in the casting of thin-walled superalloy structures, such as engine support vanes.
- A CSIR engineer, Euodia Kruger, has been seconded to Volvo Aero to work on the aerodynamic design of advanced turbine concepts for EU Framework projects.
- The CSIR's mechanical testing laboratory has been upgraded in partnership with Snecma Moteurs to undertake fatigue testing of titanium and super-alloy-based components for commercial aircraft engines and is currently developing an internationally accepted quality system adhering to ISO17025.
- The CSIR has been included in the EU FP6 project VITAL (EnVIronmenTALly Friendly Aero Engine), which aims to reduce the noise, fuel use and polluting emissions from aircraft. (See article on p 33.)
- Some CSIR engineers will work on PhD studies at Durham University in the United Kingdom, undertake the refurbishment of the CSIR turbine test rig and develop appropriate international networks. This is aimed at ultimately developing CSIR-based unique testing capabilities to validate low-pressure turbines destined for the next generation of airliner engines.
- The CSIR has maintained its six-year membership on the Society of Automotive Engineers Aerospace Committee on Engine Condition Monitoring that creates international engine safety and analysis standards for both commercial and military gas turbines.
- South Africa and the CSIR have maintained national membership of the International Symposium on Air Breathing Engines since the early 1980s, which is the only international forum on gas turbines.

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Technology migration in gas turbines	
Atar 09K50	**Volvo RM12**
• 1960s design based on a 1940s design • Simple turbojet, single spool cycle • Welded fabrications • 6,15:1 pressure ratio • NACA65 type compressor, subsonic blading • Hydraulic controls • Impingement cooled NGV, uncooled rotors. Afterburner ring flame stabilisers • Converging nozzle	• 1980s design • Advanced low bypass ratio twin spool cycle • Single crystal castings • 27:1 pressure ratio • Transonic compressor blading with controllable guide vanes • FADEC controls • Massively film cooled NGVs and rotors with internal serpentine passages • Cooled cooling air • Reduced length combustor cans and afterburner with radial flame holders • Converging/diverging nozzle

CSIR activities in light detection and ranging

By Dr Jan van Aardt, Dr Anton du Plessis, Dr Christoph Bollig and Corné Eloff

Introduction

Although light detection and ranging (lidar) has been used for monitoring the world's natural resources since the mid-to-late 1980s, it is still regarded as a relatively recent remote sensing technology. Lidar, which is based on laser technology, can rightly be considered the optical analogue of the better-known ranging technique of radio detection and ranging (radar). A lidar measures a certain quantity of light at a distance to the lidar system.

Its technology is based on simple principles, but requires advanced technology to implement. Different types of lidar exist; all of them dependent on a laser to emit laser pulses and for the detection system too. The laser pulses are sent out into the atmosphere and the light is scattered back either from atmospheric particles or from a "hard target". Taking the speed of light into account, it is possible to determine the distance to the measurement point by measuring the time it takes for the light to return to the lidar. The most important types of lidars are:

- **Range finders** determine the distance to a target and are widely used in industrial and military applications. Mounted on an aircraft, they can be used to determine ground and vegetation profiles
- **Gas and pollution detection lidars:** The so-called "Differential Absorption Lidar" (DIAL) can detect gas concentration versus distance. It relies on the characteristic light absorption features of gases. Typical applications are water vapour measurements and air pollution monitoring
- **Wind lidars** can remotely measure wind speed versus distance. Applications range from global wind field measurements from atmospheric and weather research to air-traffic safety
- **Backscatter lidars** measure the distribution of atmospheric particles called "aerosols" versus distance. They are used to monitor the concentrations of dust, smoke, haze and thin clouds in the atmosphere.

While most lidars are ground-based systems, it is worthwhile noting that all of these are also operated on aircraft platforms by the US National Aeronautics and Space Administration (NASA) and European aerospace agencies such as ESA. Range-finding and backscatter lidars are already incorporated on satellites. Lidar data have obvious potential benefits for South African scientific and public institutions. Both NASA and ESA are investigating the possibility of launching a wind lidar into space for global wind measurements.

Corné Eloff, Dr Christoph Bollig, Dr Anton du Plessis and Dr Jan van Aardt observing lidar signals on an oscilloscope.

At the CSIR, lidar research is carried out in various research areas: natural resource assessment applications; built environment characterisation; and lidar sensor development.

Lidars in forestry

Forest applications can serve as useful examples for describing the various types of range-finding lidars. An airborne profiling lidar literally acquires range information in a transect (linear) sampling scheme, thereby providing the researcher with a profiled "slice" of the target area. One can typically think of a graph that depicts height on the y-axis and distance on the x-axis. This provides a side-view of a forest that very effectively highlights the range of heights along that transect, e.g. tall trees, pioneer species and so-called "ground hits". But what about the surrounding vegetation structure?

Small-footprint lidar sensors emit pulses at very high frequency, typically in excess of 30 kHz. Each of these pulses travels to the target and based on beam divergence at the sensor, will typically yield a footprint of <1 m diameter. These pulses are emitted in a zig-zag scanning pattern as the plane travels across the landscape and the sensor sweeps across the direction of travel. Airborne, small-footprint lidar data typically have point densities of >2 hits per square meter, since the plane can acquire various overlapping flight lines by travelling up and down the area of interest.

As a sign of sophistication, many sensors have what is called "multiple return capabilities", meaning that a single pulse can be recorded more than once, depending on the amount of energy that is returned to the sensor at various travel times. In the forest example, a single pulse can hit the top of the tree canopy, return a portion of the energy to the sensor, and some of that same pulse energy can hit understory vegetation, in turn returning a portion of the energy of the same pulse to the sensor. Many sensors have up to five returns for each pulse, which allows researchers to characterise vegetation structure. An even-aged, homogeneous pine plantation might have a first return (top-of-canopy), followed by a second return (bulk of canopy biomass), and a final (third) return from the ground, depending on whether there is enough open space for the signal to penetrate. A more complex uneven-aged heterogeneous indigenous forest may have up to five returns, mainly due to the fact that the forest structure is typically more complex with old-age growth, understory vegetation and young pioneer species. Not only can forest structure be characterised in this manner, but by interpolating the first return hits and the last, known as the ground-return hits, it is also possible to derive top-of-canopy and ground digital terrain models (DTMs).

The result of logically subtracting the ground DTM from the canopy DTM, is the canopy height model which in turn can be used for forest inventory purposes to derive individual and average tree heights. It is important to note that the magnitude of lidar hits for relatively small areas is restrictive in terms of processing requirements, which makes the technology not quite applicable for purposes other than digital elevation model (DEM) derivation, flood mapping, building measurement, power line assessment, etc. Large-footprint lidar however offers a potential solution for sampling larger areas.

Large footprint or waveform sensors typically have footprint diameters in excess of 20 m. The energy signal is integrated across the entire footprint, which results in a height value on the y-axis and an associated energy response on the x-axis. This is a very useful technique for estimation of forest biomass, which in turn is critical to applications like carbon sink and source determination. One can literally correlate the energy response at each height to the biomass that intercepted and returned that signal. Footprints are not contiguous, but exhibit a predetermined spacing in a systematic sampling fashion, very similar to how a giant would tread across the landscape. Potential applications include derivation of global, coarse resolution DEMs, global vegetation biomass assessment, and large-area disaster management.

CSIR involvement in lidar applications

CSIR Natural Resources and the Environment is involved in forestry applications, which include structural assessment (inventory) of forest resources and investigating the spectral-structural interaction of vegetation. The latter aspect is of particular importance since it guides the interpretation of remotely-sensed imagery that is influenced by a variety of factors, among which structural variability – objects might "look" the same, but not "feel" the same, and vice versa! Other projects include characterisation of exotic and indigenous vegetation through spectral-structural data sources, as well as characterising the nature of vegetation for non-utilisation purposes, e.g. threats to power lines where tall exotic species can be removed, but indigenous species have to be managed.

The CSIR is involved in ground-based lidar development for application to the detection of atmospheric gases. This method of remotely determining gas densities at high accuracy is one of the most widely used applications of lidar world-wide, especially in pollution monitoring. An interesting new application of this technology is a current project involving the detection of isoprene emission from living plant material, in particular Eucalyptus plants. Isoprene is termed a biogenic volatile organic compound and is of interest in atmospheric chemistry studies, since it plays an important role in the formation of ozone and NOx. These molecules (ozone and NOx) can also potentially be targeted with lidar technology; this is currently being pursued as a potential research topic at the CSIR National Laser Centre.

The CSIR Satellite Applications Centre views airborne lidar technology as a complementary technology to precision correct remote sensing products. Application requirements from the broader user community highlighted the need for 3D terrain models of metropolitan areas with very high resolution imagery as a backdrop. Planning for World Cup 2010, for instance, could benefit from lidar technology through 3D reconstruction of stadiums with computer-aided design (CAD) software utilising lidar ground and non-ground points. The potential also exist for military and safety and security institutions to improve their spatial intelligence using this technology.

The future

This exciting technology offers many novel opportunities that the CSIR is exploring. South Africa is already on its way to becoming one of the few nations that can boast a hyperspectral satellite in space.

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CSIR expertise to contribute to environmentally friendly aircraft aero-engine design

CSIR expertise on turbine technology has led to the organisation's inclusion in the European Union Framework 6 (FP6) project titled VITAL (EnVIronmenTALly Friendly Aero Engine). French aerospace company Snecma is the lead partner in the VITAL consortium of 53 partners.

Reduction of noise, fuel use and pollution emissions from aircraft is seen as one of the highest priorities by the Advisory Council for Aeronautical Research in Europe. In response to environmental goals set by this body and the Kyoto Protocol, VITAL is working on a major advance in developing the next generation of commercial aircraft engine technologies. Potential benefits to the European aero-engine industry include high-performance, low-noise and low-emission engines at an affordable cost. These benefits will also accrue to customers, air passengers and society at large. VITAL's main objective is to achieve a six decibel noise reduction per aircraft operation and a 7% reduction in carbon dioxide (CO_2) emissions over engines in service prior to 2000.

The CSIR's Glen Snedden and his team will work on low pressure turbines with partner Avio SPA (Italy), particularly experimental turbomachinery and turbine computational fluid dynamics (CFD) for increased engine efficiency. This reduces the quantity of fuel an aircraft needs to take on board and lowers the overall weight.

Areas under investigation in other subprojects include consideration of the modularity of gas turbine engines in general. The role of low speed fans in engine noise reduction and optimisation of the compressor performance are critical areas of investigation. Furthermore, an investigation into the use of advanced lightweight materials incorporated into an engine is explored in an effort to minimise the mass of the engine.

Describing the research on the low pressure turbines to be undertaken by the CSIR, Snedden comments, "We will focus on the effects of airfoil wakes (namely unsteady flows) on the performance of non-axisymmetric profiled endwalls of turbine rows. An endwall is the cylindrical surface onto which the turbine blades are mounted; profiling endwalls changes the shape from pure cylindrical to a landscape of mounds and depressions. This change in geometry has been shown to reduce loss generating vortices in the near wall region caused by the low momentum fluid found there."

Design of the profiled endwalls will take place at Avio. "Profiled endwalls are a relatively new development and little is understood about their performance under unsteady conditions," Snedden explains. "We will do the experimental work at the CSIR in the low-speed rotating axial turbine rig." Numerical work will also be conducted at the CSIR which has a strong track record in CFD calculations, in particular with steady flows; Avio will partner with the CSIR for the unsteady analysis.

The CSIR's current knowledge development on non-axisymmetric endwall profiling on axial turbines includes Snedden's PhD studies registered at Durham University. His team will include Dwain Dunn and Ndumiso Zwane, both enrolling for higher degrees as part of this opportunity.

Dr Kamalluddien Parker, National Contact Point on aerospace for the Department of Science and Technology, remarks, "The nature of our interaction here is indicative of the level of confidence that aerospace original equipment manufacturers place on our capabilities. This is the first inclusion of South Africa in an aerospace-related research area, funded under the EU FP6 and as such, augurs well for our involvement with other aerospace initiatives. It is imperative that the South African research establishment engages at this level in an effort to re-establish itself in the global aerospace S&T fraternity."

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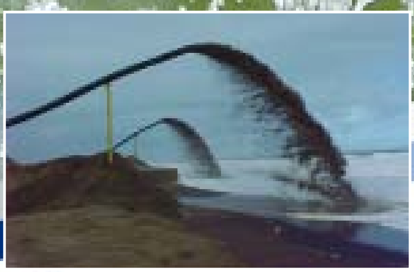
VITAL

VITAL is an EU FP6 Theme 4 "Aeronautics & Space" Integrated Project running for four years, which aims to significantly reduce aircraft engine noise and CO_2 emissions. It has a total budget of 90 million euros, including 50 million euros in funding from the European Commission. Snecma leads a consortium of 53 partners gathering together all major European engine manufacturers: Rolls-Royce Plc, MTU Aero Engines, Avio, Volvo Aero, Techspace Aero, Rolls-Royce Deutschland and ITP, and the airframer Airbus. The work described above will be performed under subproject (SP) 6 "Low Pressure Turbine" / Work Package (WP) 6.2 "Ultra Highly Loaded Turbine" in collaboration with partner Avio SPA (Italy). http://www.project-vital.org

NEWS



Dredger tailings discharged to the inter-tidal zone on the Namibian coast. Image courtesy: Namdeb Diamond Corporation

Action needed
to reduce impact of diamond mining in Benguela region

South Africa, Namibia and Angola need to consider additional environmental management and monitoring actions to better understand and mitigate the effects of discharged sediments resulting from near-shore and coastal diamond mining. This advice is contained in a report, compiled under the leadership of the CSIR, on the cumulative effect of discharges resulting from such mining activities in a defined area in the Benguela Current Large Marine Ecosystem (BCLME) region.

It is estimated that 400-800 million tons of sediment from the Orange River was discharged from 1968 to 2005 in this area. In comparison, it is estimated that about 400 million tons of sediment resulted from near-shore and coastal diamond mining during the same period.

The research project was one of 75 linked to the BCLME, which received funding to the tune of R65 million through the United Nations Development Programme (UNDP) over the past four years. The BCLME programme aims to pave the way for the three countries of the Benguela – Angola, Namibia and South Africa – to manage the region's valuable marine and coastal resources and to strike a better balance between human needs and conservation issues.

The Benguela current region is situated along the coast of southwestern Africa, stretching from east of the Cape of Good Hope in the south, northwards to Cabinda in Angola and encompassing the full extent of Namibia's marine environment.

The BCLME programme acknowledges that nature does not heed man-made boundaries – environmental problems occur across national boundaries. As part of this programme, marine scientists and experts from Angola, South Africa and Namibia have pooled their resources for the past four years, working on numerous projects to protect the ecosystem of one of the most productive ocean areas in the world, the Benguela current region.

CSIR sediment dynamics specialist and leader of the project on sediment discharges from diamond mining, Geoff Smith, says in recent years some diamond mining operations have resulted in the discharge of up to several million tons of tailings at a single site annually.

"Several future mining operations are planned to be of a similar scale. This study was rooted in a concern that cumulative effects, over time and space, may be severe," Smith explains. The project area covered a section of the Namibian coastline from the Olifants River (in the south), to Spencer Bay (in the north), and from the high-water mark extending to 40 m in depth.

Other findings included:

- Natural sediment (from the Orange River) and windblown sediment tend to be fine. Most of the sediment discharged from mining, however, is medium to coarse sand. The fine sediment is mobilised by wave action and is transported rapidly, generally northward, by wind and wave-driven currents. This is not the case with coarse mine sediment, which generally results in accretion.
- The discharge of large volumes of sand can result in long-term (years to decades) deposition on reefs, which overshadows natural trends. By 2013, an estimated total of about 3 km of rocky inter-tidal and near-shore subtidal smothering of reef in the demonstration areas will occur. This translates to less than 1% of the study shoreline.

Recommendations put forward include that detailed logs should be kept of the hourly and daily rates of all sediment discharges, as well as accurate directional wave measurements and wind data in mining areas.

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Water is essential to all aspects of life, yet 99% of the water on earth is unsafe or unavailable to drink. Some 1,2 billion people globally lack safe water to consume and 2,5 billion do not have access to adequate sanitation. Its estimated that 9 500 children die world-wide every day from water-related diseases and a lack of clean drinking water. Water is an economic issue as it is essential for poverty reduction, agriculture, food and energy production.

CSIR helps raise awareness about global humanitarian water crisis

A documentary, intended as a global call to action regarding the evolving world water humanitarian crisis, made its debut in South Africa when it was screened at the CSIR in November.

Running Dry, written, produced and directed by Jim Thebaut and narrated by Jane Seymour, sets out to raise awareness regarding the worsening global humanitarian water crisis, a message that is particularly relevant in South Africa. The film focuses on life-and-death crises with water and sanitation in China, India, South Asia, South Africa and the Middle East. Mrs Lindiwe Hendricks, Minister of Water Affairs and Forestry, hosted the event and delivered the keynote address. The event was organised by the CSIR and Thames Water of the UK. The project was inspired by former US Senator Paul Simon's powerful book, "Tapped Out".

Speaking at a media briefing before the event, CSIR water expert Bettina Genthe said the CSIR was acutely aware of the urgency to address water issues in southern Africa. Research efforts are focused on assessing and managing water resources to ensure an optimal supply of quality water to users, while ensuring the integrity of the resource so that economic growth and prosperity is realised despite environmental constraints. This research is conducted in the areas of groundwater, water ecosystems, health and governance and is in line with the CSIR's commitment to improving quality of life and growing the economy, both nationally and regionally.

Running Dry producer Jim Thebaut (front right) and narrator Jane Seymour received a warm welcome at the CSIR at the first screening in South Africa of the film. With them are CSIR President and CEO, Dr Sibusiso Sibisi (front left), Sir Paul Lever of Thames Water (behind Thebaut) and CSIR Group Executives Dr Hoffie Maree and Khungeka Njobe (at the back)

Safe drinking water from the sun

A simple, low-cost technique to provide safe drinking water, and thereby avoid waterborne diseases such as cholera, dysentery and polio, is the subject of a new European Union-funded project. The CSIR is one of three African participants in the project.

The SODISWATER project aims to demonstrate that water can be disinfected using only a water bottle and a steady supply of sunlight. This technique can help vulnerable communities in developing countries that do not have a reliable, safe water supply, who might find themselves exposed to natural or man-made disasters.

According to the World Health Organisation (WHO), over 1 billion people around the world have no access to any kind of treated drinking water. Every year 1,6 million people, most of them young children, die of diarrhoeal diseases such as cholera that are attributable to a lack of access to safe drinking water and basic sanitation. Millions more are infected with waterborne parasites.

Solar disinfection has been approved by the WHO and is commended for its proven efficiency in the aftermath of the Tsunami disaster in southeast Asia in 2004.

Martella du Preez, a senior researcher at the CSIR, says the technique is simple: Water is placed in a clear bottle and shaken vigorously to aerate the water. Under the heat of the sun, the water soon reaches temperatures in excess of 45°C. Combined with ultraviolet radiation from the sun, this will inactivate many viruses, bacteria and parasites within a few hours. Even turbid water can be disinfected using this method.

Over the next three years, the multi-disciplinary research group will investigate the factors that influence communities to adopt or reject SODIS; whether the basic technique can be improved using simple technologies and whether there are any major waterborne diseases that cannot be prevented through SODIS. The team comprises the Kenyan International Community for the Relief of Suffering and Starvation, the Institute of Water and Sanitation Development in Zimbabwe, the Royal College of Surgeons in Ireland (RCSI), the University of Ulster, the University of Leicester (both in the United Kingdom), the Swiss Federal Institute of Aquatic Science and Technology, the University of Santiago de Compostela and the Plataforma Solar de Almeria, both in Spain.

As part of the agreement, CSIR researcher Eunice Ubomba-Jaswa has travelled to Ireland to take up a three-year PhD research position under the supervision of Dr Kevin McGuigen, Department of Physiology and Medical Physics at the Royal College of Surgeons in Ireland. She will spend 18 months in Ireland and England and then move to Spain to complete her experiments.

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Sea conditions and cholera outbreaks researched in Mozambique

CSIR environmental researchers are investigating the potential role that various sea conditions play in cholera outbreaks. The researchers are focusing their efforts on an area in Beira, a coastal city in Mozambique.

Cholera is an acute bacterial infection of the small intestine, caused by *Vibrio cholerae* and characterised by massive diarrhea with rapid and severe depletion of body fluids and salts. The bacteria enter the body via the mouth, usually in contaminated water or foods, and cause an infection in the mucous membranes lining the lumen of the small intestine.

The project focuses on environmental conditions of the disease and not on the social conditions promoting outbreaks. The multi-disciplinary team investigates the ecology of the bacteria to determine whether there are linkages between cholera outbreaks in the area and various land and sea conditions. They are developing a model based on the data related to certain environmental factors and the number of cholera cases.

While research continues, preliminary findings indicate that the area is an environmental reservoir for the bacteria. The research team has found patterns and consistencies in the data relating to environmental factors and cholera outbreaks. The cholera bacteria have also been identified in samples taken along the coast line of Beira and in the estuary close to the city. The team investigates the entire landscape and analyses remotely sensed as well as *in situ* data on parameters, such as air and sea surface temperature, chlorophyll in the sea and rainfall.

Cholera bacteria survive in the sea and can contaminate marine resources such as shellfish. Using remote sensing data, the researchers investigate the overall pattern of the occurrence of chlorophyll and its potential link with cholera. Researchers in other parts of the world have shown the bacteria to be associated with the zooplankton. The cholera bacteria are carried by copepods – a zooplankton – and where there is chlorophyll, zooplankton are found.

"The CSIR research team, comprising earth observation experts, mathematical and statistical modellers, microbiologists and oceanographers, will continue their work to generate evidence to prove, or disprove, the potential sea-based link," says research leader Marna van der Merwe.

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Design: Loretta Steyn Graphic Design Studio
Printing: Lesogo Print and Marketing
Compiled by: CSIR Communication

www.csir.co.za ISSN 1017-4966
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