South Africa’s Space Programme of the mid-1980s to mid-1990s: Driver towards a South African Titanium Industry

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Materials Science and Manufacturing

7 October 2010

Outline of presentation

- Introduction
- Drivers of the International Titanium Industry
- Titanium in South Africa’s Space Programme of the mid 1980s to mid 1990s
  - Product development for satellites
  - Spin-off applications: hip stems
- Towards a South African Titanium industry
  - The innovation opportunity
  - The Titanium Centre of Competence
  - Progress on R&D and technology platforms
- Relevance for the Current SA Space Programme
- Conclusions

Introduction

Background

- The South African Space Programme of the mid ’80s to mid ’90s resulted in fascinating achievements in mastering and applying specialised technologies
- Individuals who participated in this high-tech programme later contributed strongly in other demanding industry sectors
- Experience gained through developing technologies for processing the Ti-6Al-4V alloy to produce satellite components prepared me for a leading role in today’s South African Titanium Strategy
- The talk will show how this strategy supports the current South African Space Programme

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Properties of Titanium

- Titanium is the 4th most-abundant structural metal on earth
- The density of titanium is only about 60% of that of steel
- The tensile strength compares favourably to stainless steels, iron-base superalloys and cobalt-base alloys: its specific strength is much higher
- The commercial alloys of titanium are useful to temperatures of about 540ºC to 600ºC
- Titanium is exceptionally corrosion resistant - exceeds that of stainless steel and has outstanding corrosion resistance in the human body and in seawater

Drivers of the International Titanium Industry

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Drivers of the International Titanium Industry

Cold War:

Titanium in military aircraft (USA)
Titanium in submarines (USSR)

Space Missions:

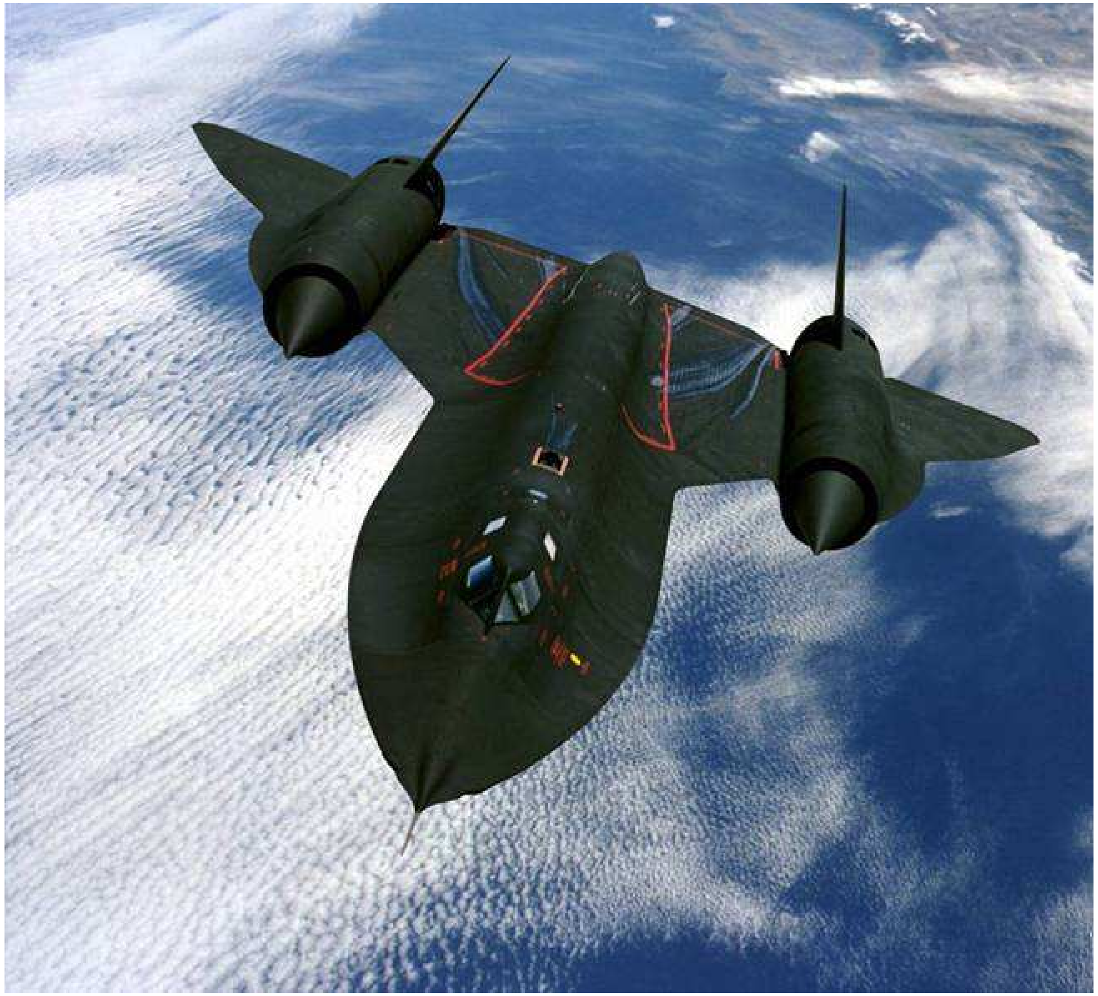
Titanium in satellites
Titanium in launch vehicles

Commercial Aircraft:

From less than 4% in Boeing 747 to >17% in Boeing 787
Similar increase for Airbus
Growth of >50% expected over the next decade

Cold War: Titanium in Military Aircraft of the USA

The SR-71 Blackbird



Designed & built in 1959 - 1963

Fastest airplane ever:
Mach 3.2 (3700 km/h)
at 80 000 ft ~ 24 km
New York - Londen: 1h 55min

Fuselage skin temperature:
200º - 370ºC
Needed to be lightweight

Constructed for 90%+ from
Titanium alloys

50 million pounds Ti used during
development
67 tonnes per SR-71

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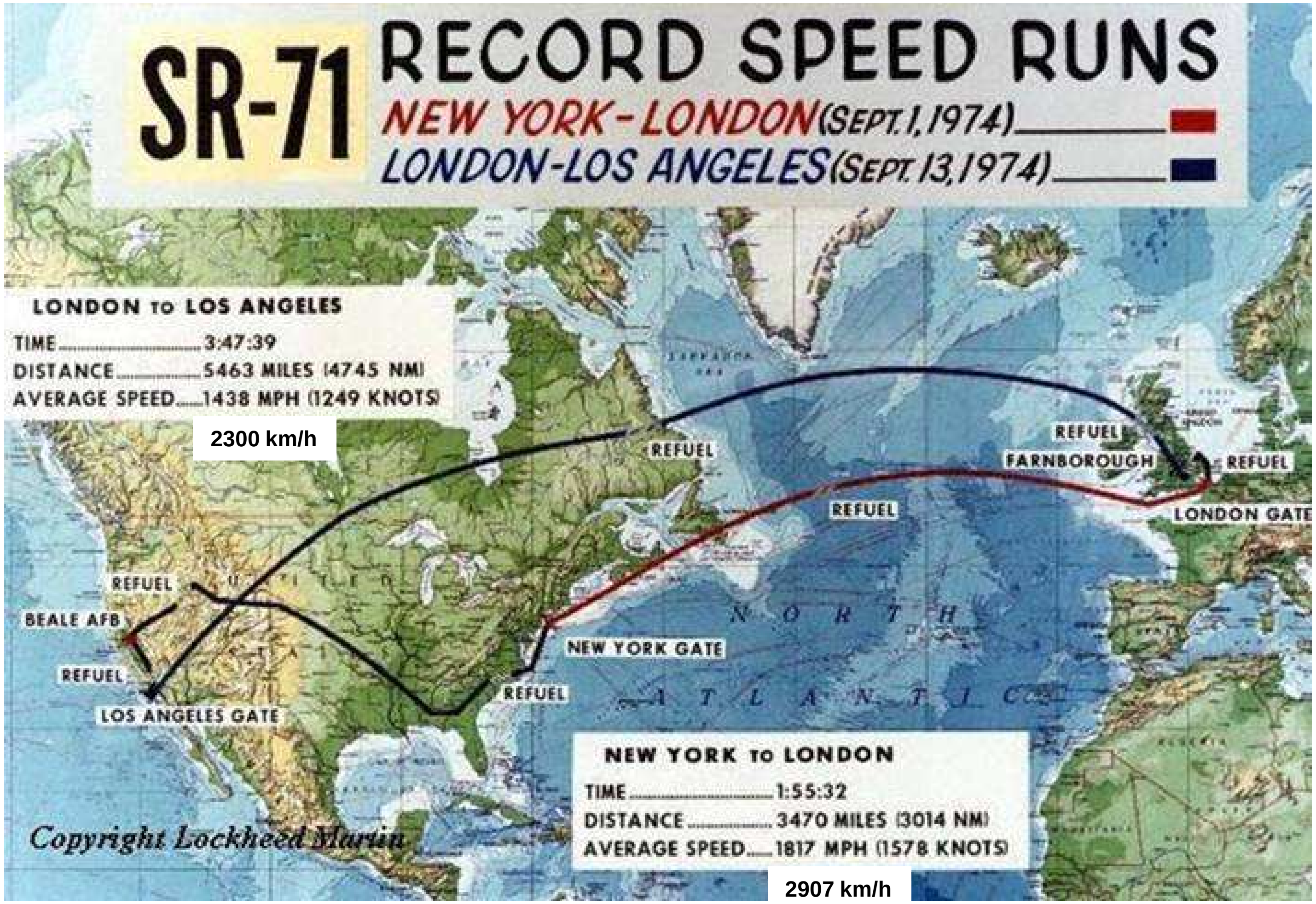
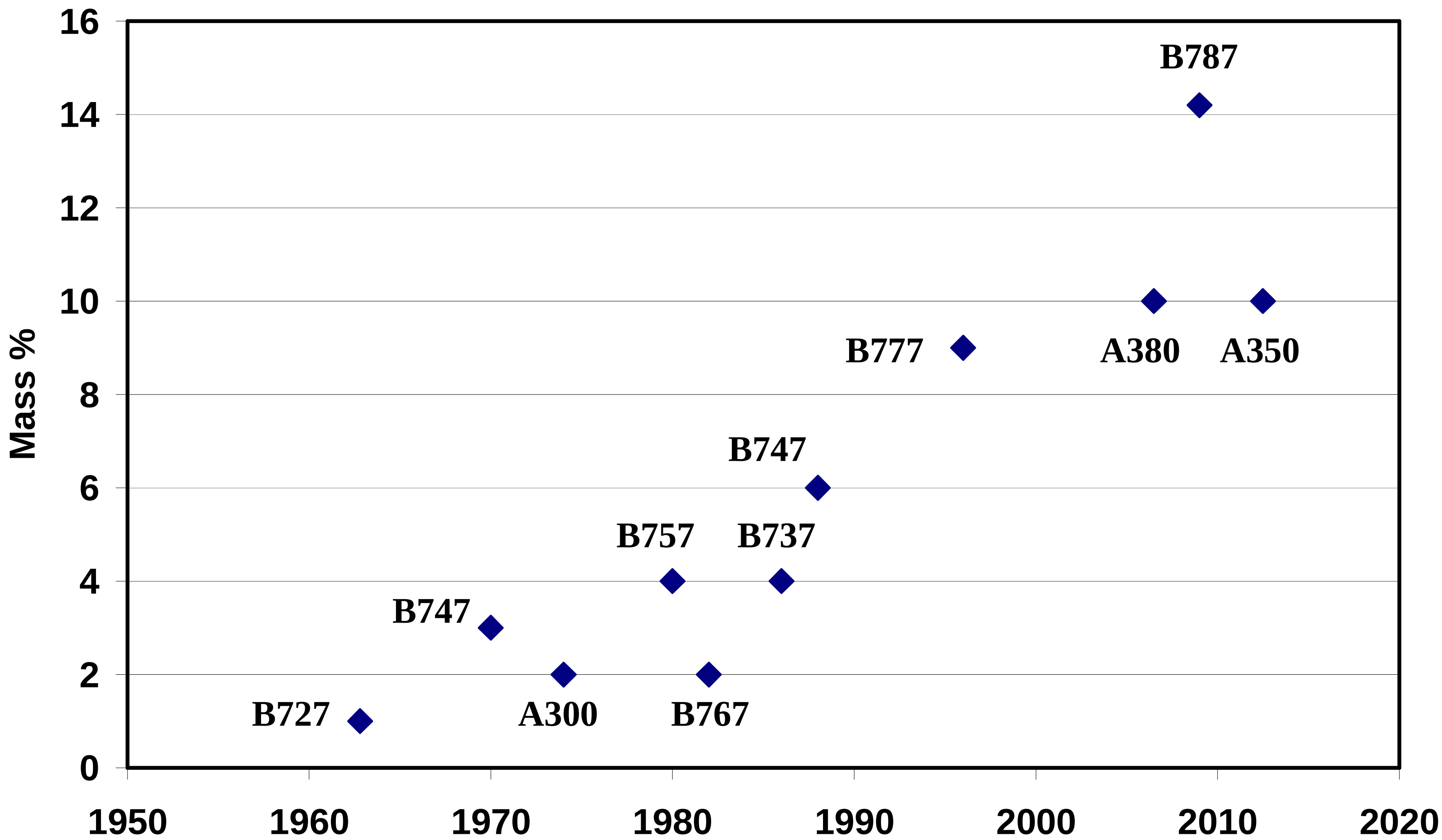
SR-71 Performance



2300 km/h

2907 km/h

Titanium Content per Airframe



(J. Monahan, ITA Conference, 2006)

Titanium in South Africa's Space Programme

of the mid 1980s to mid 1990s

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Developing Satellite Components: The Challenges

- Titanium (Ti-6Al-4V) in high pressure vessels on satellites
- User specifications were provided
- Manufacturing processes had to be developed
- Manufacturing facilities and equipment had to be established
- Products had to be qualified for use
- Test and evaluation facilities had to be established

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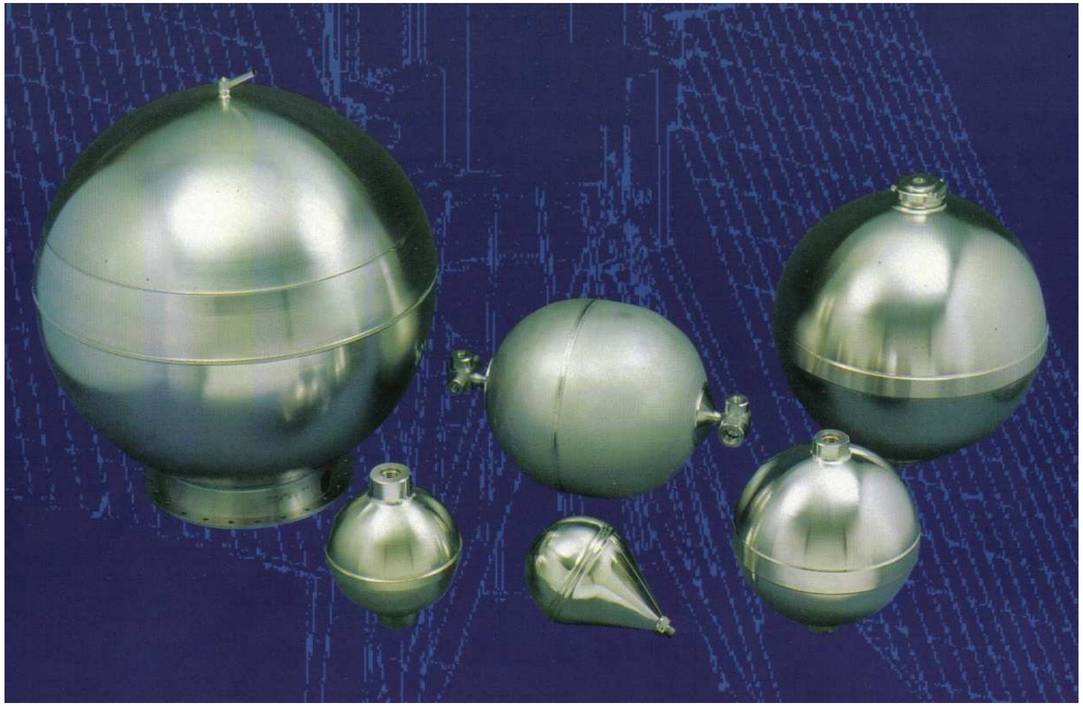
Technology Development



Technologies established:

Component & system design

Finite element based analysis

Die design & manufacture

Forging

Superplastic forming

Machining

Electron beam welding

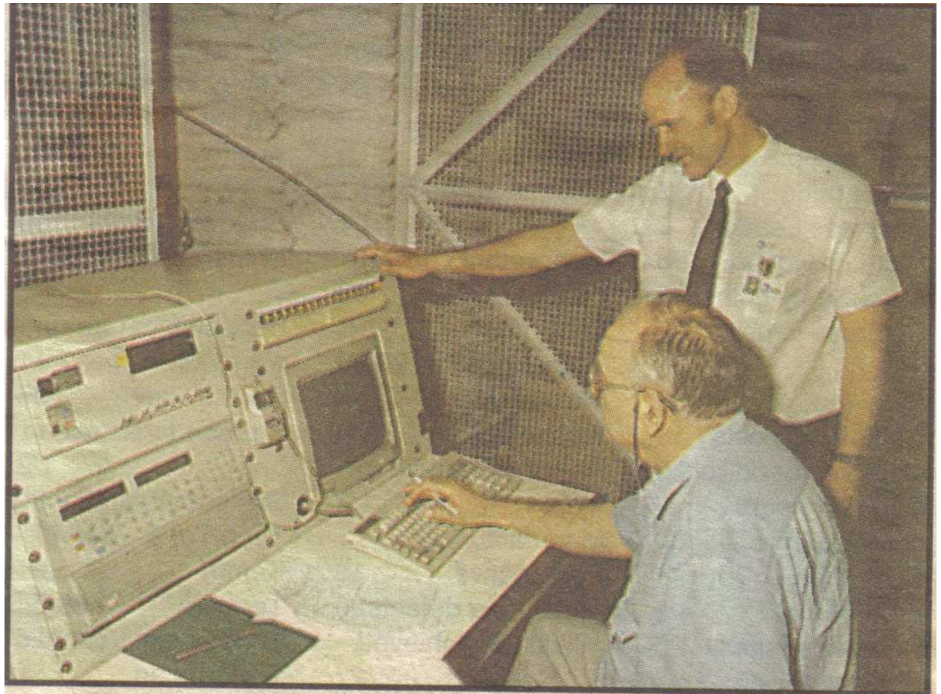
Laser welding

Non-destructive testing

(X-Ray microfocus imaging)

Test and Evaluation Facilities

Dr Willie du Preez (left) and test engineer Johan Nieuwmeijer pressurise the water filled test tank up to 36 bar.



Test division manager Bill Grant (seated) and materials technology manager Dr Willie du Preez at the control system for the pressure test. Three fuel tanks are pressure tested; two to proof pressure and the third to burst pressure and beyond.

Satellite fuel tanks put to the test, Engineering News, Vol12 No.42 (Oct 30 – Nov 5 1992)

Publication in Engineering News

MARTIN CREAMER'S
ENGINEERING News
Vol. 12 No. 42 ISSN 0257-8646 Johannesburg Price R2,50 October 30 - November 6 1992

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Satellite fuel tanks put to the test

By Robyn Leary
Assistant editor of
The Engineering News

SOUTH Africa's fledgling space industry is making steady progress as was evidenced by the successful completion of the fourth static rocket motor test two weeks ago at Somchem's Hangklip test site in the Cape. (See *The Engineering News*, October 23, 1992).

However, advances are also being made on other fronts, although not as publicly, to determine the viability of launching South Africa's own satellite.

Rosslyn-based HTP, involved in the project

• To page 2

Fuel tanks tested

• From page 1

since the initial planning stages in 1988, is currently testing its third batch of storage tanks which will eventually store propellant for the satellite's fuel system.

The tanks, manufactured from a titanium alloy (Ti-6Al-4V), each comprise two hemispheres which are initially forged at Atlantis Forge in the Cape and hot forged at Cemenco in Boksburg, says materials technology manager **Dr Willie du Preez**.

The hemispheres are then machined at HTP's facilities in Rosslyn resulting in a wall thickness of 0,8mm.

Other machining includes nozzles on the top and bottom of the tanks; an inner ring to facilitate the welding together of the two hemispheres; and a mounting flange.

The tanks also feature a bladder separating the two halves which will eventually store propellent and nitrogen gas respectively.

The company uses electron beam welding; a process he claims is relatively "unique" in South Africa as only four such welding machines exist in the country: three at HTP and one at Simera.

The tanks, each worth an estimated R150 000, also have to undergo rigorous testing to ensure they will be able to operate effectively once the satellite is launched.

In addition to a leak test, they have to undergo both a bladder and a pressure test.

A strain gauge test is also carried out to measure the deformation of the tank while under pressure.

Two tanks, each weighing 3,6 kg, will be attached to the satellite when it is launched.

•ENGINEERING NEWS CLUES (011) 622 3744 or circle No 286 on the page 46 coupon.

Commercialised Satellite Fuel Tanks from Ti-6Al-4V

APOGEE Aerospace INDUSTRIES INC.

PROPELLANT AND HIGH PRESSURE TANKS

TECHNICAL SPECIFICATIONS

	AAI 10/0	AAI 20/0	AAI 40/0	AAI 50/0	AAI 60/0	AAI 70/0
Volume (dm^3)	9.3	0.8	0.7	35	2.3	4.5
Diameter (mm)	295	134	112	420	182	209
Length (mm)	330	167	166	470	210	340
Mass (kg)	17	2	0.15	4.5	3.5	2.4
Material	Ti-6Al-4V	Ti-6Al-4V	Ti-6Al-4V	Ti-6Al-4V	Ti-6Al-4V	Ti-6Al-4V
EPDM diaphragm	No	No	No	Yes	No	Yes
Operating pressure (bar)	980	550	51	22	414	31
Burst pressure (bar)	1900	1510	140	46	1130	80
Propellants/pressurant	He	N_2	He/N_2H_4	N_2H_4	N_2	N_2H_4

Spin-off Application: Locally Developed Hip Stem

Key technologies utilised:
Engineering design & analysis
Die design & manufacture
Forging
Machining
Hydroxyapatite coating

F A Weber, W B du Preez and N D L Burger, *Development and use of the Hybrid stem for upper femoral bone loss in hip revision surgery*, Geneeskunde, Vol 35, No 3, (May 1993) p 14

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Towards a South African Titanium Industry

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Strategic Highlights

1999: National Research and Technology Foresight Project recommends Ti metal and TiO_2 production from South African raw materials

2002: Publication of the Integrated Manufacturing Strategy by the **dti** and the National Research and Development Strategy by the DST

2002/3: Development and approval of the Advanced Manufacturing Technology Strategy (AMTS)

2002-5: Establishment of the Advanced Metals Initiative as implementation initiative

- 4 Pillars: Light Metals Development Network (LMDN), PMDN, NMDN, F&BMDN

2006: DST contracted CSIR to lead the LMDN

- Focus on Titanium and Aluminium

2003-5: Development of the SA Aerospace Strategy

2009: CSIR contracted by DST to establish the South African Titanium Centre of Competence

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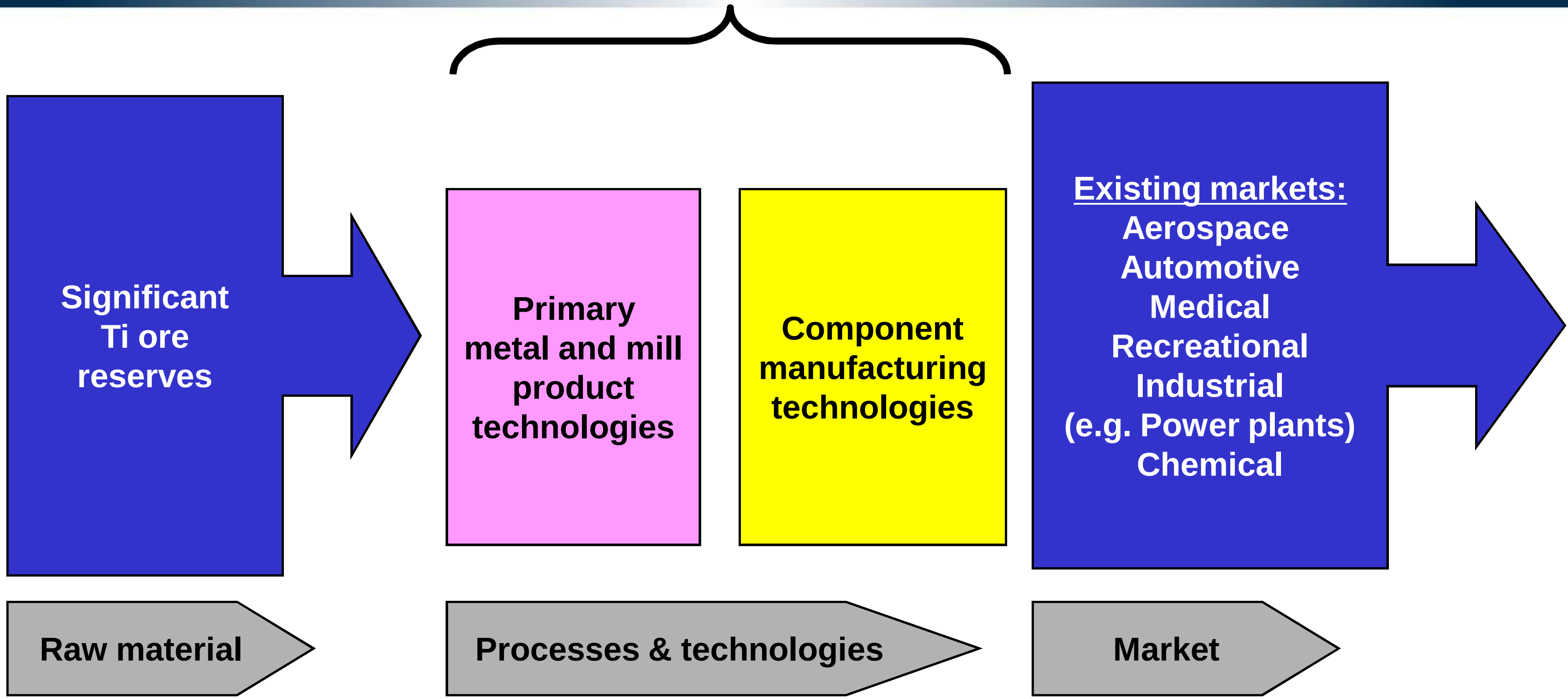
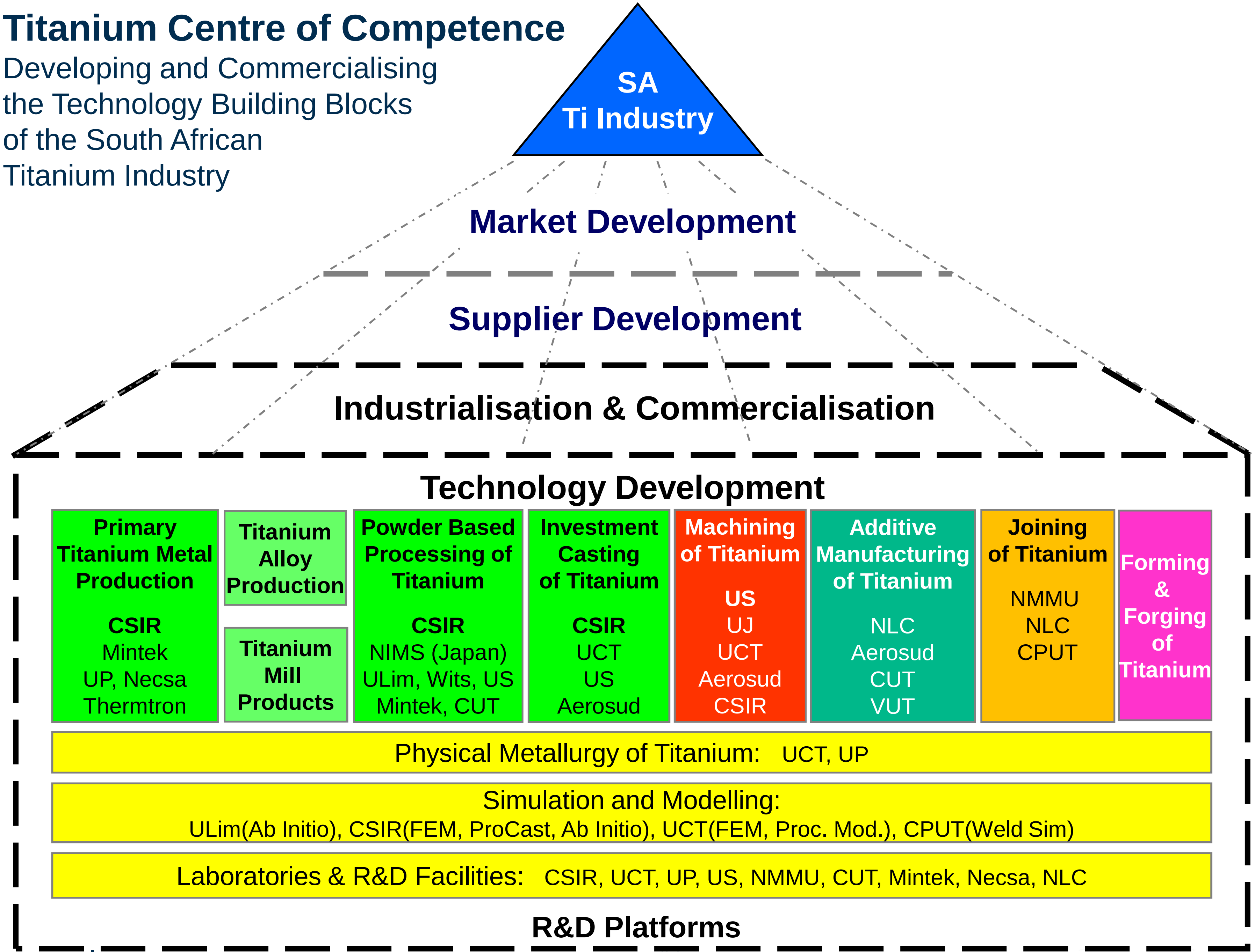
The South African Innovation Opportunity



The Titanium Centre of Competence integrates and coordinates R&D and commercialisation across the value chain

Titanium Centre of Competence

Developing and Commercialising the Technology Building Blocks of the South African Titanium Industry

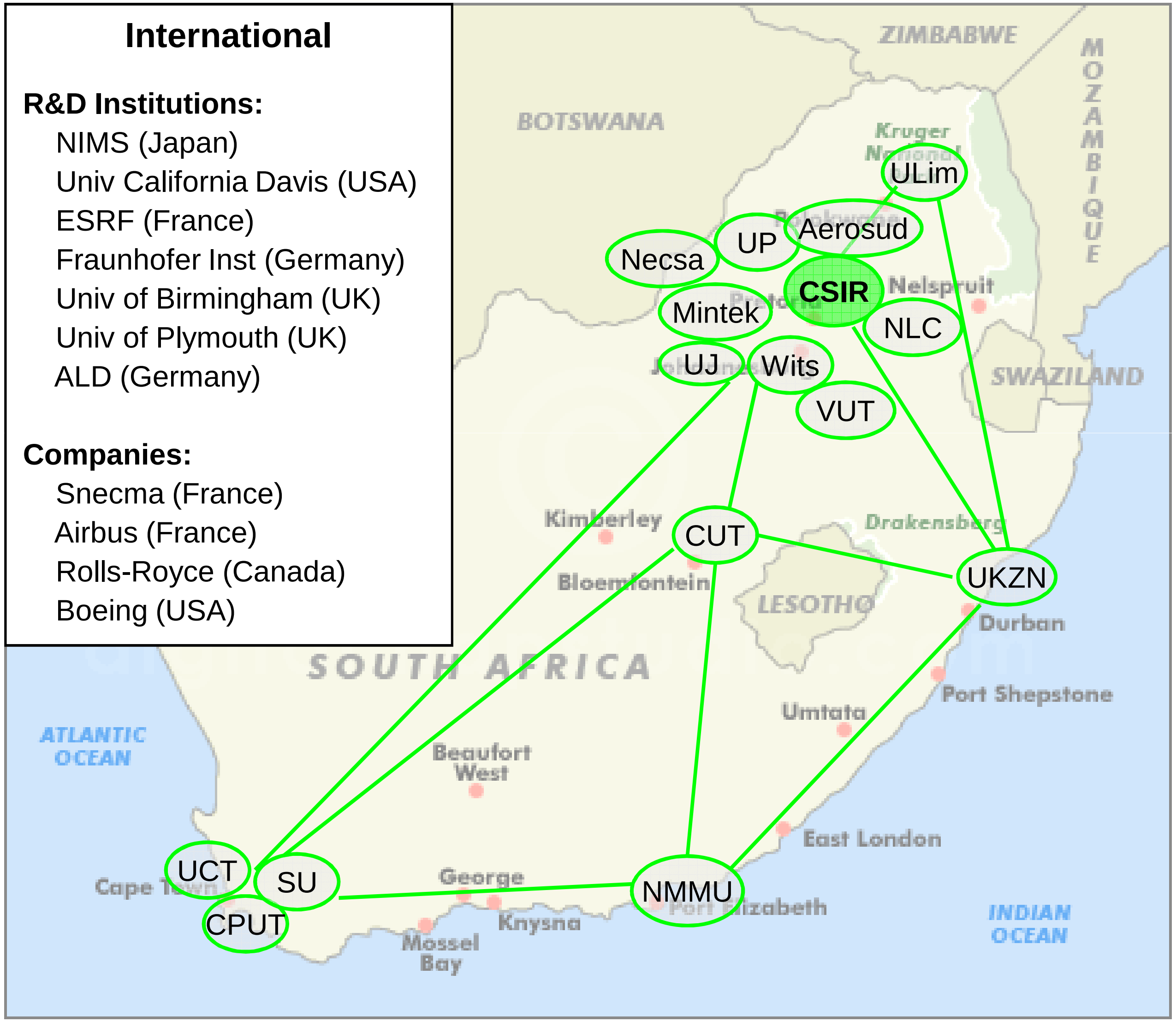


Titanium Centre of Competence Collaborators

International

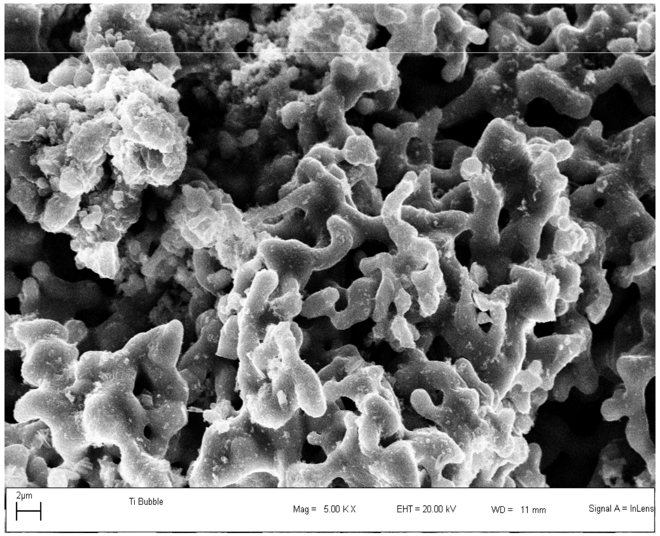
R&D Institutions:
- NIMS (Japan)
- Univ California Davis (USA)
- ESRF (France)
- Fraunhofer Inst (Germany)
- Univ of Birmingham (UK)
- Univ of Plymouth (UK)
- ALD (Germany)

Companies:
- Snecma (France)
- Airbus (France)
- Rolls-Royce (Canada)
- Boeing (USA)

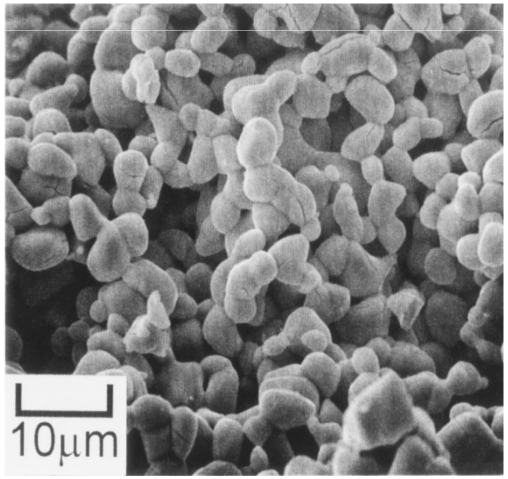


Primary Titanium Production

- Primary Titanium Production
  - First Titanium powder produced
  - Demonstration of continuous processes
  - Pilot plant in 2011



CSIR powder



Commercial powder

Investment Casting of Titanium Alloys

- Only a few players in the world can cast Titanium successfully on commercial scale
- They handle this as proprietary knowledge and do not publish detail
- CSIR had to develop the key processes in the casting process chain
- We upgraded facilities used successfully in the 1990s for casting turbine blades in Nickel-based superalloys, to enable us to investment cast Titanium alloys

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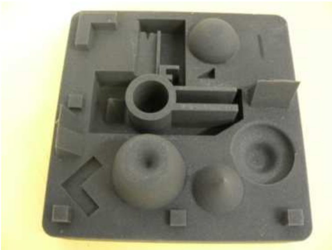
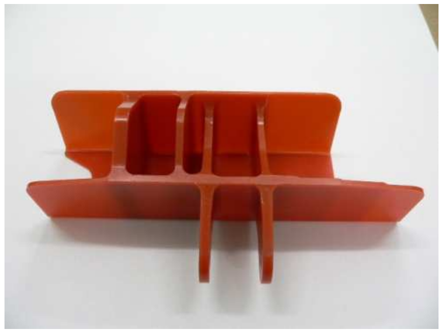
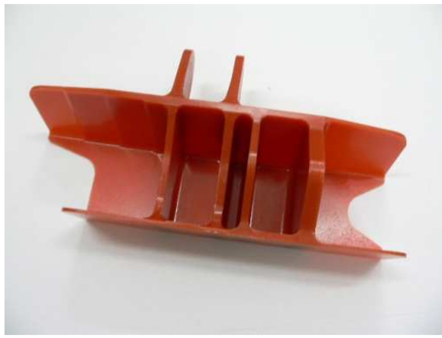
Investment Casting of Titanium Alloys

- Developed and packaged the Titanium mouldmaking and crucible melting processes



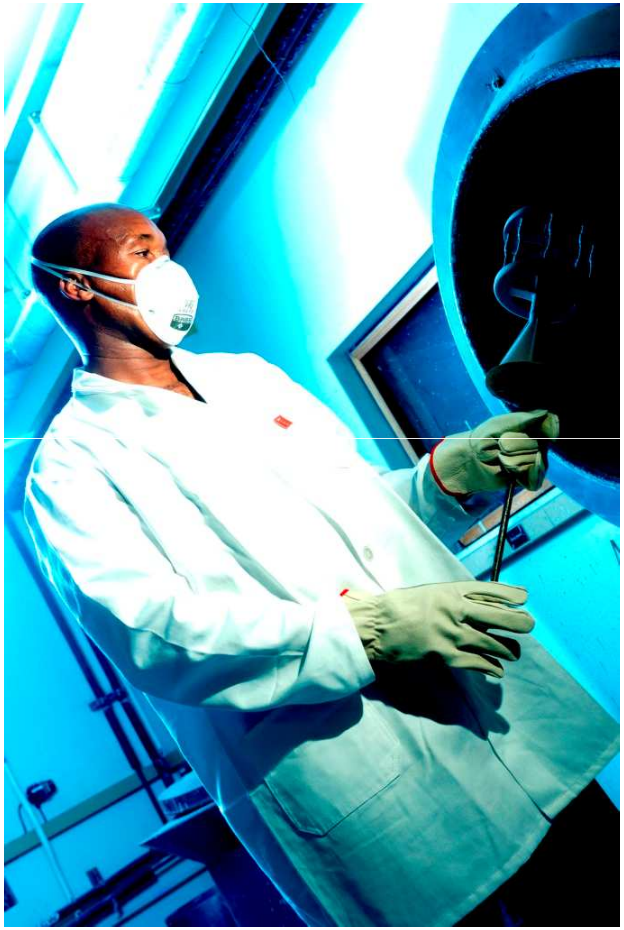
- Developed and packaged the chemical milling process

- Casting an aerospace demonstrator part

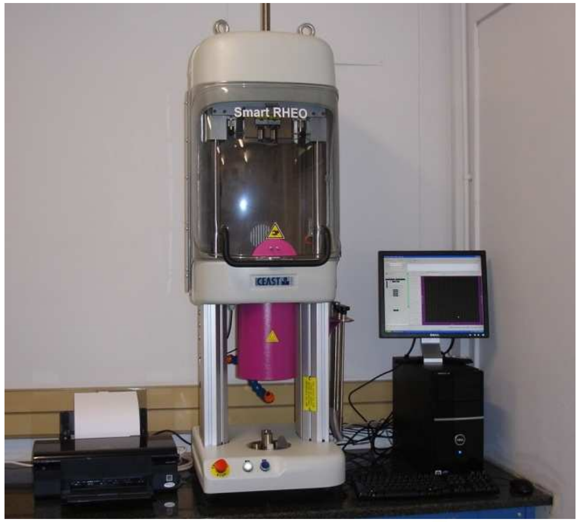
Commercialisation of Investment Casting of Titanium

- Find industrial/commercial partner
- Decide on technology transfer to existing operation or to incubate new enterprise
- Proceed with industrialisation and commercialisation



Titanium Powder Processing

- Our primary Titanium metal production process delivers a Titanium powder
- More affordable Titanium powder will unlock a much broader market for Titanium products produced from powder
- Therefore we have been developing a Titanium powder processing competence since 2006
- Through strong support from the DST we have been able to acquire essential equipment



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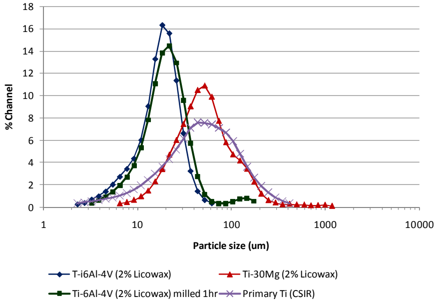
Titanium Powder Processing

- Establishment of metal injection moulding process
- Development of own binder

- Patent on novel Ti-Mg alloys via direct reduction of TiO_2

TiO_2 & Mg → HEBM / MA / RM → Mixture of oxides & TiMg → Leaching → TiMg

- Compaction and sintering of powder produced through the CSIR process



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The CSIR Team

AMTS High Performance Machining (HPM) of Light Metals with an Emphasis on Titanium and Selected Alloys

- Main Objectives
  - Build world class competence in HPM of light metals
  - Increase competitiveness of SA firms to become part of the global supply chain of high added value components
- Research and Development Focus Areas
  - Consolidation of high performance machining knowledge base for light metals
  - High performance machining of Ti and Ti alloys in raw or near net shape forms
  - High performance machining of integral Ti parts
  - Optimisation technologies for machined Ti components
- Consortium Members
  - Stellenbosch University
  - University of Johannesburg
  - University of Cape Town
  - Fraunhofer Institute for Machine Tools and Forming Technologies

Rapid Product Development Labs

Dept. of Industrial Engineering
University of Stellenbosch
Private Bag X1
Matieland
7602
South Africa

Tel: +27 (0)21 808 4241
Fax: +27 (0)21 808 4126
Email: dimitrov@sun.ac.za

Rapid Product Development Labs

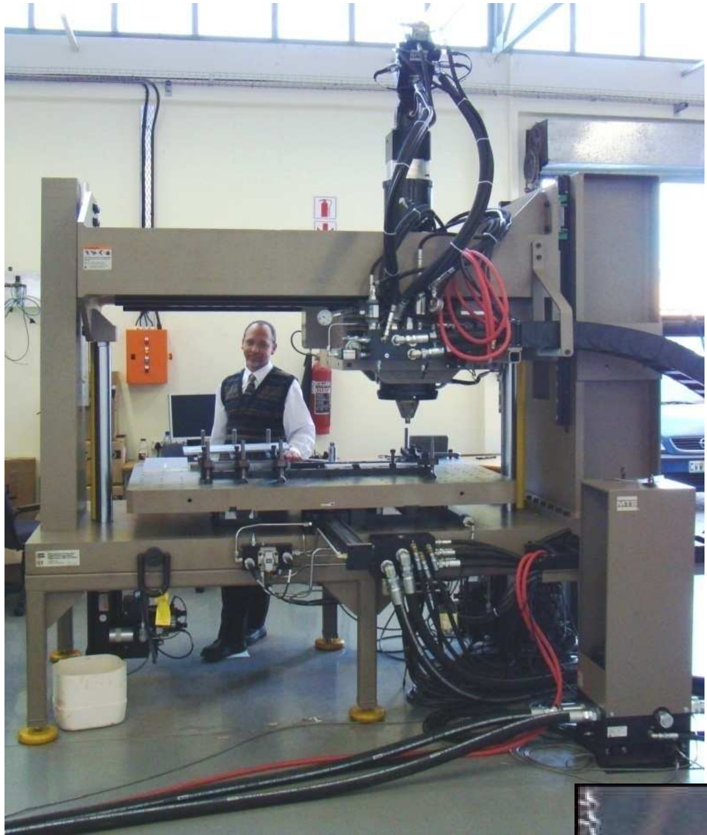
Additive Manufacturing of Titanium

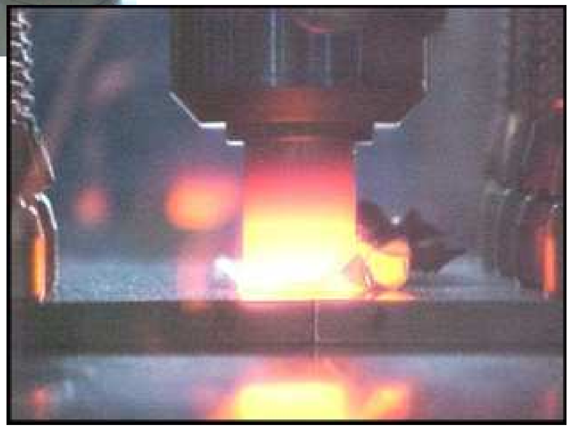
Direct laser sintering of Titanium to produce medical implants

Images courtesy Prof Deon de Beer, VUT

Central University of Technology, Free State

Friction Stir Welding of Titanium





Nelson Mandela Metropolitan University

for tomorrow

Relevance for the Current SA Space Programme

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National Competence Developed with DST Support

- The Titanium Centre of Competence provides access to 60 - 70 local researchers and technologists, linked to international experts
- A student pipeline has been established, with up to 30 postgraduate students involved in the programme at any point in time
- Titanium products and metal processing technologies for the manufacturing needs of the Space Programme can be developed locally

Conclusions

Conclusions

- Titanium and its alloys, which are key for many components in satellites and launch vehicles, will be locally available in future
- Through sustained investment of the Department of Science and Technology, the CSIR, other science councils and universities, a strong local resource and expertise base on titanium and its processing has been established
- The Titanium Centre of Competence is integrating and coordinating R&D and commercialisation across the titanium value chain and is well positioned to serve the South African Space Programme

Thank You

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