Put your systems on an Aluminium diet
Applying well-known materials using innovative manufacturing techniques.
(Extreme lightweighting, direct Al polishing)
Ronald Halfwerk, Rik ter Horst, Niels Tromp
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Issues for cryogenic instrumental design:

- CTE differences (bimetallic effect, lens mounts)
- Vacuum
- Unknown or unpredictable behavior at low temperatures (Composites)
- Weight
- Stiffness

Design strategy:

Design with only *one well known material* for both, optics and mechanics, as much as possible

Temperature Invariant System

Manufacture to accuracy
(no adjustments)
Our choice: Aluminium

- Conventional material with well-known material properties
- Used for both mechanical structure and mirrors

Applying:

New production methods:
- 5-axis simultaneous milling

New design techniques and strategies:
- Extreme lightweighting of mechanical structures

New polishing techniques:
- Direct optical polishing of aluminium surfaces
Direct polishing of aluminum surfaces (for optical grade surfaces)

Why using this technique?:
- Avoid bimetallic effect
- Accurate and smooth surface figure
- Low light scattering
- In-house manufacturing

Scattering comparison (laser 543 nm)

Diamond turned sample  Polished sample

5-axis milling (= common practice)

A typical 5-axis milling machine.

Example of configuration of milling axes of a 5-axis milling machine.
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Using Astron Xtreme Light Weighting

- Title: CONSTRUCTION ELEMENT, METHOD AND APPARATUS FOR MANUFACTURING A CONSTRUCTION ELEMENT, COMPUTER PROGRAM AND MIRROR

Traditional v.s. New method
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Comparing open vs closed back light weighting

<table>
<thead>
<tr>
<th>Part #</th>
<th>Light weighting method</th>
<th>Wall thickness</th>
<th>Mass</th>
<th>Displacement</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Open back</td>
<td>2</td>
<td>100</td>
<td>4.8E-4</td>
<td>0.529</td>
</tr>
<tr>
<td>2</td>
<td>Closed back</td>
<td>1.48</td>
<td>100</td>
<td>3.45E-4</td>
<td>0.374</td>
</tr>
<tr>
<td>3</td>
<td>Closed back</td>
<td>0.6</td>
<td>510</td>
<td>4.34E-4</td>
<td>0.250</td>
</tr>
</tbody>
</table>

~ -50% of mass reduction but retained stiffness!

Lose weight without penalty to stiffness

New Principle of light weighting

- creating the pockets from two or more sides in such a way that they will form an efficient structure
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Advantages Astron X L W
In general:
- Higher stiffness to weight ratio
- Higher natural frequency
- Monolithic and Homogenous
- Thinner and higher rib/wall production possible (~0.3 mm/100 mm), because all sides of the ribs and walls are interconnected
- Reduction of part size for same stiffness
- Reducing part count (no lid + bolds)
- Highly symmetrical structures (less problems with global deformation due to internal stress)
- More freedom of design

For Cryogenic applications:
- Better heat transfer because of shape of structure
- Shorter cooling/heating cycle

Disadvantages Astron X L W
In general:
- More complex in design and manufacturing
- Design and production both require more complex CAM soft- and hardware
- Longer milling times
- For a given part size a larger (5-axis simultaneous) milling machine is needed
- Outsourcing of parts is less likely because of complexity and the need for increased communication (Design for Manufacturing)

In Cryogenic applications:
- Internal cleaning might be more difficult

In Optical applications:
- Because of holes and intersecting pockets: unwanted light can exit

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Competitive Alternatives:

- Carbon Fiber Reinforced Polymer (CFRP)
  - + very strong structures
  - - CFRP is a radical change in design/manufacturing technology (€++)
- Honeycomb glued structures
  - + Cost effective
  - - less freedom of design
- In general:
  - AXLW has smooth transition to (future) ceramics materials

Case study light weighting:
Spectrometer Main Optics (SMO) of MIRI

James Webb Space Telescope

Typical 1 m.
Case study* – Basic additional costs due to light weighting

- Design time (approx 20%++)
- Production time (approx 2x)
- Additional R&D, extra fixtures, testing (non-linear increase), see table below

<table>
<thead>
<tr>
<th>Amount of closed back light weighting used (90% lw)</th>
<th>0%</th>
<th>12.5%</th>
<th>25%</th>
<th>37.5%</th>
<th>50%</th>
<th>62.5%</th>
<th>75%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change of SMO mass, kg</td>
<td>0</td>
<td>-1.2</td>
<td>-2.4</td>
<td>-3.5</td>
<td>-4.7</td>
<td>-5.9</td>
<td>-7.1</td>
</tr>
<tr>
<td>Increase in additional costs</td>
<td>0%</td>
<td>11%</td>
<td>14%</td>
<td>18%</td>
<td>24%</td>
<td>37%</td>
<td>65%</td>
</tr>
</tbody>
</table>


Case study SMO – assumptions

Into account is taken, for the Spectrometer Main Optics (SMO):
- Currently known total SMO mass is 21kg (open back light weighting method used)
- Only 90% of total SMO mass is light weightable
- Of all light weightable mass (18.9kg) only for 75% can be switched to light weighted with the new method, the rest is not suited. So at least 25% will always be light weighted with the old method.
- Traditional method light weights to around 80%, new method about 90%
- Out of a total SMO cost of $5.5 million, $1.2 mln is for design and production (44% for design, 56% for production)

And for MIRI:
- Total estimated cost $169.- mln.
- 1 kg of SMO weight reduction equals about 1 kg of solid coolant extra in space
- 1 kg of solid coolant equals about 3 months lifetime, equals roughly 1 month viewing time (JWST has three instruments)
- An estimated lifetime of 10 years
Case study SMO – Increase in total cost

Increase in total cost in relation to SMO mass reduction due to the use of closed back light weighting (non-linear increase in additional costs included)

<table>
<thead>
<tr>
<th>SMO mass, kg</th>
<th>21</th>
<th>19.8</th>
<th>18.6</th>
<th>17.5</th>
<th>16.3</th>
<th>15.1</th>
<th>13.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design</td>
<td>100%</td>
<td>114%</td>
<td>120%</td>
<td>127%</td>
<td>136%</td>
<td>154%</td>
<td>190%</td>
</tr>
<tr>
<td>(weighted 44%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production</td>
<td>100%</td>
<td>118%</td>
<td>128%</td>
<td>140%</td>
<td>155%</td>
<td>180%</td>
<td>229%</td>
</tr>
<tr>
<td>(weighted 56%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>116%</td>
<td>125%</td>
<td>134%</td>
<td>147%</td>
<td>169%</td>
<td>211%</td>
</tr>
</tbody>
</table>

Case study light weighting: Spectrometer Main Optics (SMO) of MIRI

- Conclusion: using the new method on 50% of the light weightable mass at an SMO cost of almost 6.1 mln dollars (=0.5% MIRI budget) will increase the MIRI viewing time with almost 5 months.
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First application of AXLW in the X-shooter spectrograph:

Cold optics box
Balance arm


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General applications of Astron Xtreme Light Weighting:

- In small structures: maintaining stiffness
- In large structures: reducing weight
- Thin walled structures: reducing buckling
- Applicable materials for AXLW:
  - All materials suitable for milling
  - All materials suitable for ultrasonic machining

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On New Business Development
-Different shapes for AXLW

On New Business Development
-Application overview Xtreme Light Weighting

Possible areas of application are applications that can be related to:
- Extremely low weight structures
- High stiffness/strength to weight ratios (optical, aerospace, pick-and-place)
- Monolithic parts
- Homogenous material properties (cryogenics)
- High accelerations of parts (mechanisms, robotics, photolithography, launch into space, racing engines)
- ‘By design’ higher natural frequency (launch into space)
- Longer instrument lifespan (cryogenic space application)
- A small space envelope (miniaturization, reduced part size for same stiffness)
Application domains and applicable materials (summary)

The envisaged application domains are:
- 1. High-speed precision positioning systems
- 2. Avionics
- 3. Space applications (as pay-load e.q. instruments and equipment)

General applications of Astron Xtreme Light Weighting are:
- In small structures: maintaining stiffness
- In large structures: reducing weight
- Thin walled structures: reducing buckling

Applicable materials for eXtreme Light weighting are:
- All materials suitable for milling
- All materials suitable for ultrasonic machining

Acknowledgements:
Niels Tromp (Inventor), Ramón Navarro, Rik ter Horst

Thank you for your attention
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This patented ‘Extreme lightweighting technology’ is available through licensing and technology transfer programmes.

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