Illustrated Summary Report on

Design and Development of a Wheelchair Enablement Device

Pyra-Aid™ “Life Without Obstacles”

See Video of Development / Testing on:

http://www.youtube.com/watch?v=9D_J80lWfcY

Solid Model Design of Pyra-Aid™ J. Roberts

John Roberts, Final Year Mechanical Engineering

Student Conceived Capstone Project

Life Without Obstacles

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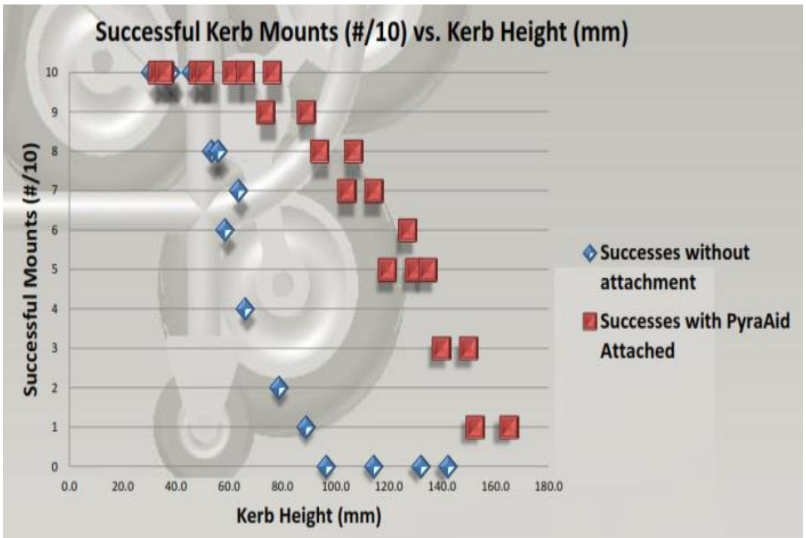
Summary

1% of the population of the Western World gain mobility and freedom though daily use of wheelchairs[1] – a mobility often restricted by every day barriers including the mounting of steps/kerbs and particularly stressful in road crossing. Solution inspiration arises from the humble 3 wheeled industrial hand truck. Design criteria, identified through wheelchair user group liaison, include operation, efficiency, safety, attachment, universality, aesthetics and cost. The progressive design, development and testing of Pyra-Aid™, a retro fitted, user friendly, momentum powered mechanical device to aid kerb mounting is undertaken. Field testing of three iteratively developed prototypes has proven to be very promising.



PyraAid™ Enablement Device Prototype Iterative Design, Development and Testing by J. Roberts

See Video of Development / Testing on: http://www.youtube.com/watch?v=9D_J80lWfcY

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Abstract

With 3 million users in the US and 5 million users in Europe[1], a staggering 1% of the total population of the Western World are estimated to gain mobility and freedom though the daily use of wheelchairs. Unfortunately, this mobility can be severely restricted by every day barriers such as mounting single steps or kerbs.

The progressive design, development and testing of Pyra-Aid™, a retro fitted, user friendly, momentum powered mechanical device to aid in mounting of single steps or kerbs, is undertaken. A systematic design approach, informed by wheelchair user and support group liaison, is adopted in the iterative development of the enablement device. Critical design criteria of the innovative 3 wheeled pyramid configuration include operation, efficiency, stability, safety, ease of attachment /detachment, versatility, wheelchair brand universality, manufacturability, aesthetics and cost.

Design optimisation of the developing device, utilising state of the art manufacturing and material selection methodologies, is undertaken. Advanced analytical, computer aided design and experimental techniques, including finite element analysis and photo-elastic testing, are employed in the development of the novel wheelchair kerb mounting device.

Pyra-Aid™, a generation progressive device, has been manufactured and tested both in field and laboratory. Kerb height variable field performance, mass optimisation and labour / materials cost comparisons of the three iteratively designed, developed, manufactured and tested prototypes are undertaken. Initial step / kerb mount tests of the mark 1, 2 and 3 momentum powered wheelchair enablement device prototypes have proven to be very promising.

Recommendations for future work, including further advanced user centric device operation optimisation / testing and product commercialisation, are presented.

Solid Model Design of Pyra-Aid™ J. Roberts

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1. Pyra-Aid™ Need and Inspiration

Liaison with the Irish Wheelchair association, Health Research Board and Amputees Ireland provided an invaluable insight into living with disability issues. In particular, significant wheelchair mobility issues in relation to mounting of steps / kerbs affecting the independence of the disabled community were identified, including:

- Accessibility - Ramp location, Crossing roads, Single steps
- Users Individual Strength
- Ability to Balance during Climb

The apprehension experienced by some wheelchairs in road crossing and overcoming the obstacle of a kerb on opposite side can barely be appreciated by the non-wheelchair user. The loss of independence and mobility due to inability to mount kerbs/ steps can be severely restricting.

Progressing from a multidisciplinary third year group project(7), in which the author was Design and Innovation Lead, this final year individual capstone project concerns the design optimisation of the developing kerb mounting device, utilising state of the art manufacturing and material selection methodologies. Advanced analytical, computer aided design and experimental techniques, including finite element analysis and photo-elastic testing, are employed in iterative prototype development / optimisation.

Structured and user centric multidisciplinary team brainstorming exercises(7) led to Inspiration arising from a most unlikely industrial application source - the humble but highly effective 3 wheeled industrial hand truck used to transport loads over steps and stairs.

Figure 1
3 Wheeled Industrial Hand Truck
(Photo J. Roberts)

Figure 2
J. Roberts
Original Trade
Metal Fabricator
(Photo J. Roberts)

The author's pre-student practical experience and trade as a metal fabricator was a further significant contributing factor in the decision to continue to advance the journey from concept solution generation through progressive customer driven systematic design, iterative prototype development / manufacture and experimental / field testing.

Pyra-Aid™

Life
Without Obstacles

2. User Driven Systematic Design

A systematic design approach and methodologies, informed by wheelchair user and support group liaison, is adopted in the iterative development of the enablement device.

Higher-Level Objectives	Lower-Level Objectives
Safety of user and Third party persons	Quality Customer Appeal
Mount Curbs of Max Height	Minimum Space
Convenient to use	Simple Mechanism
Robust	Cost Effective
Cost	Material Properties
Meets ISO Standards	

Figure 3 Pyra-Aid™ Determination of Higher and Lower Level Objectives

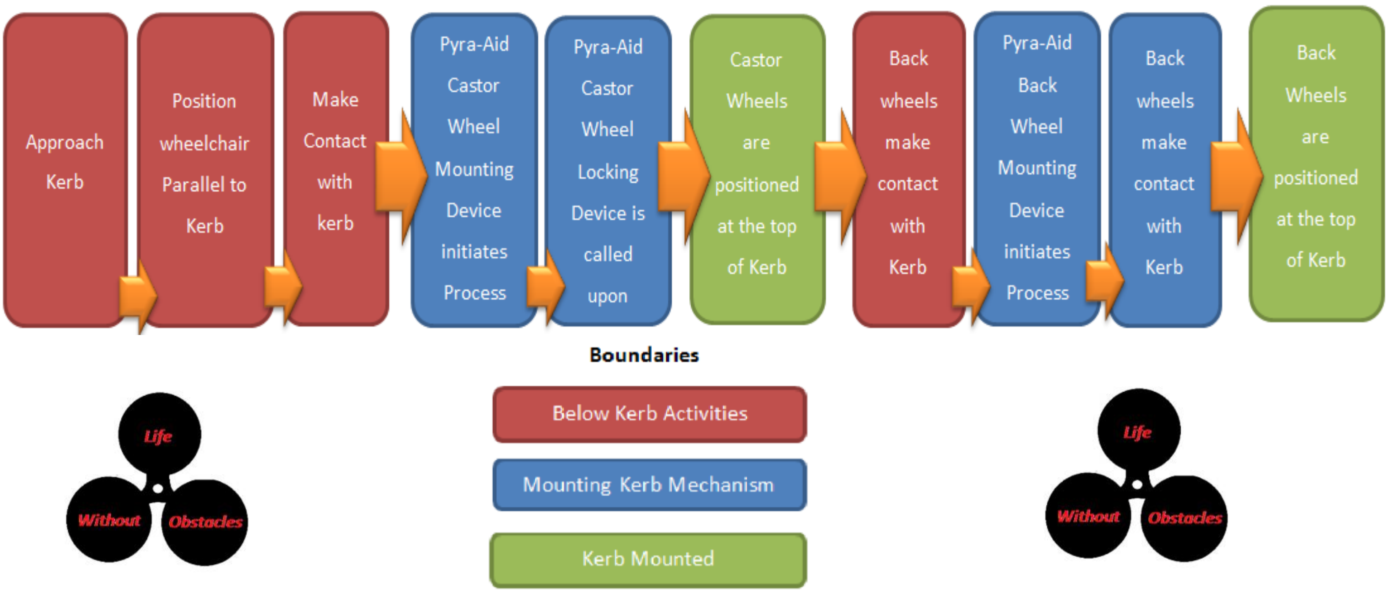

Figure 4 Pyra-Aid™ Systematic Design Process Block Diagram

The determination of user requirements was driven by extensive consultation with user and support organisations / individuals including: Irish Wheelchair Association, Munster Amputees, Health Research Board, MMS Medical, StyLite Designs, HSE and Community Care Services.

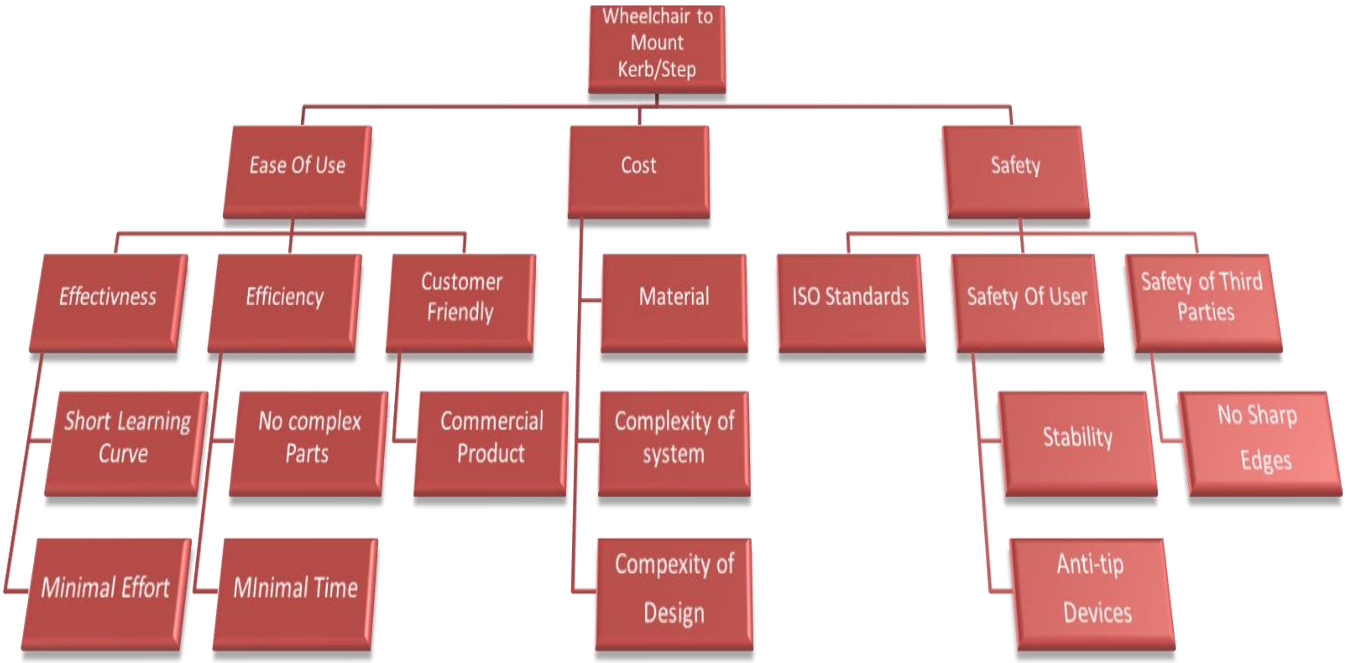

Figure 5 Pyra-Aid^{TM} Wheelchair User Driven Systematic Design

Wheelchair User Driven Critical Design Criteria determined include

- Operation
- Efficiency
- Stability
- Safety
- Ease of Attachment / Detachment
- Versatility
- Wheelchair Brand Universality,
- Manufacturability
- Aesthetics
- Cost

Pyra-Aid^{TM}

3. Commercial Research

Market research highlighted the number of wheelchair users who could benefit kerb mounting aid.

With 3 million users in the US and 5 million users in Europe[1], a staggering 1% of the total population of the Western World are estimated to gain mobility and freedom though the daily use of wheelchairs. Unfortunately, this mobility can be severely restricted by every day barriers such as mounting single steps or kerbs.

A number of products existing on the commercial market – Whirlwind Rough Rider, Magic Wheels, Max Sella Stair Lifter and the Free Wheel – were investigated[7] as to suitability to address the determined product critical design and operational criteria.

COMPETITORS

Competitor	Strengths	Weaknesses
Whirlwind Roughrider	➢ Designed to handle rough ground. ➢ Good stability and safety for forward tipping. ➢ Adjustable centre of gravity.	➢ Not designed for kerb/stair mounting ➢ It is a chair not an attachment therefore more expensive €610
Magic Wheels	➢ Two geared manual wheels for step climbing. ➢ Can maneuver over uneven terrain ➢ Not battery powered	➢ Very expensive €3800 ➢ User needs comprehensive and balanced upper body strength.
Max Sella Stair lifter	➢ Used to ascend normal set of stairs	➢ Does not promote user independence – requires third party ➢ Very expensive at €3050
The Free Wheel	➢ Lightweight and durable. ➢ Removable attachment. ➢ Travels on rough terrain.	➢ High degree of skill required ➢ Designed for sports application or rough terrain ➢ Not designed for kerb/stair mounting

Figure 6 Tabular Assessment of Commercially Available Products[7]

It was concluded that a major and growing market opportunity exists for a momentum powered, universal, kerb mounting aid, which is inexpensive and has little maintenance commitments.

4. The Pyra-Aid™ Solution

Pyra-Aid™ a 3 wheeled wheelchair enablement device :

Figure 7 Pyra-Aid™ Solid Model J. Roberts

Figure 8 Pyra-Aid™ Solid Model J. Roberts

4.1 Pyra-Aid™ Conceptual Design

Pyramid 3 Wheeled System

When contact occurs with the step or the kerb the momentum and force of impact is transmitted to aiding the wheelchair mount the kerb.

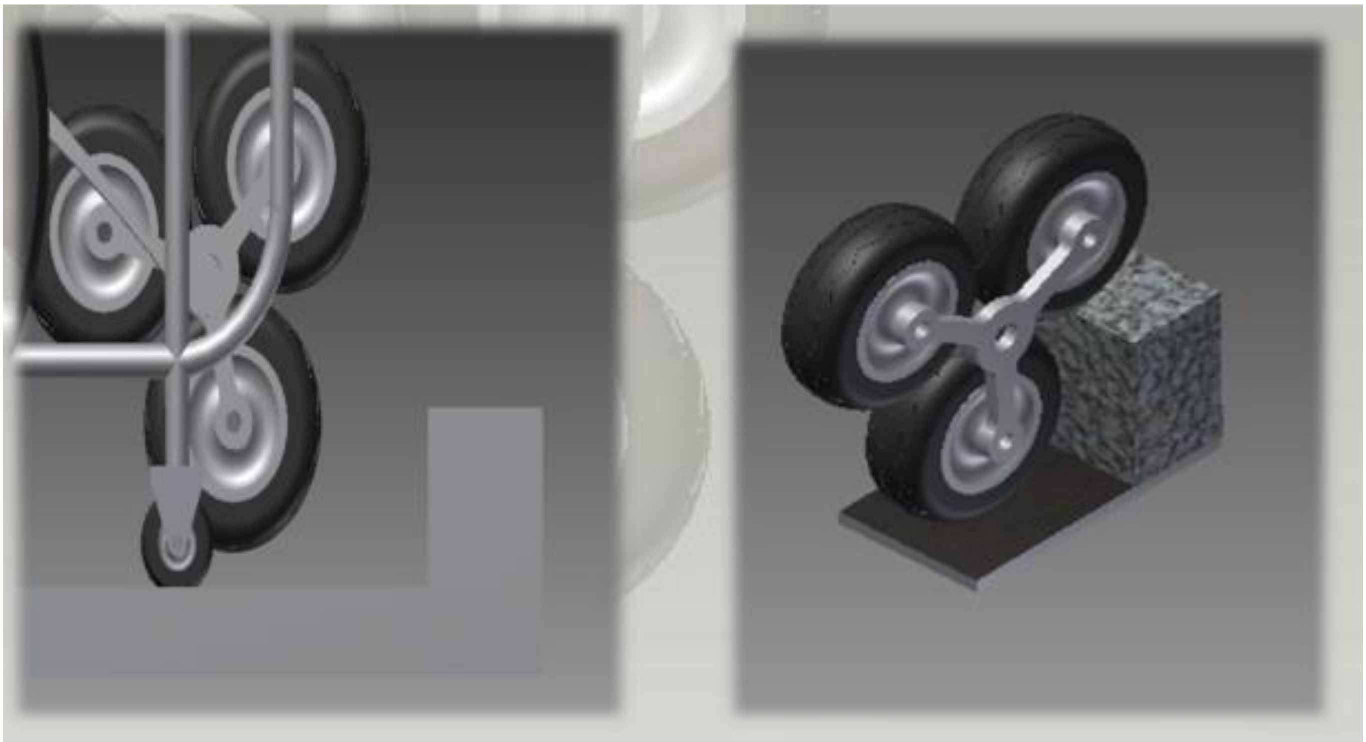

Figure 9 Pyra-Aid™ Pyramid 3 Wheeled System Solid Model
J. Roberts

Advantages

- Does not affect the manoueverability of the wheelchair as it is positioned just above the surface but is still very effective when coming into contact with kerb.
- Little maintenance needed
- Low cost
- Durable and robust
- Can be used on kerbs of different sizes

4.2 3 Wheeled Pyramid Design Positioning on Wheelchair

Concept Configurations

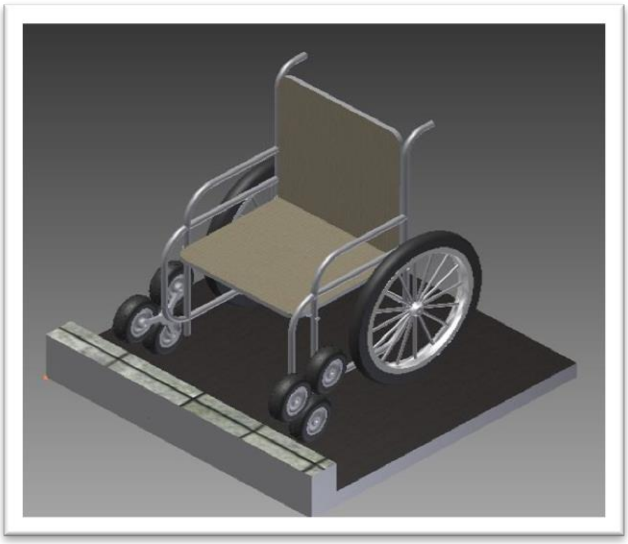

Figure 10 Pyra-Aid™ Concept Configuration 1 Solid Model J. Roberts

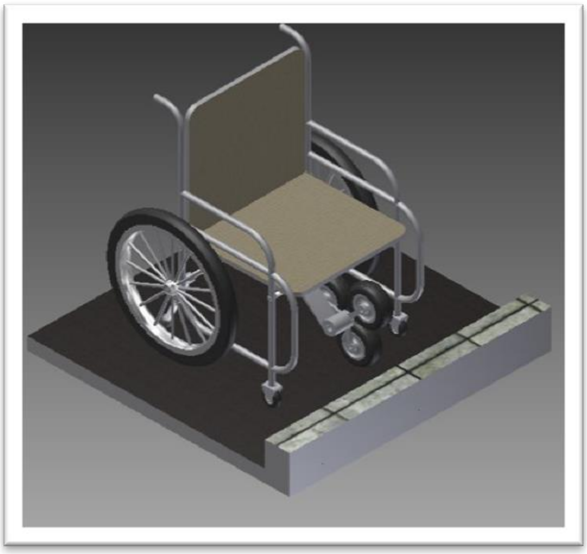

Figure11 Pyra-Aid™ Concept Configuration 2 Solid Model J. Roberts

Pyra-Aid™ concept configurations 1 and 2 were discarded as being unsuitable as they could not cater for both rigid and foldable chairs. Concept 3 overcame this universality requirement through side structure support configuration - leading to design optimisation and fabrication of the mark 1 Pyra-Aid™ prototype.

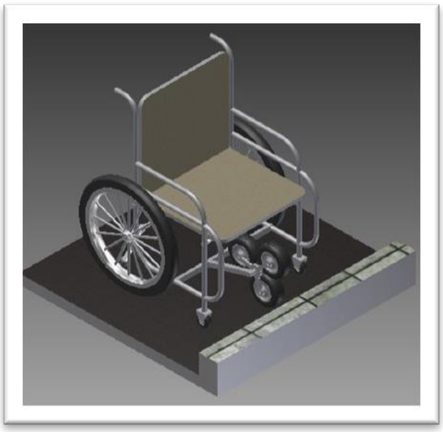

Figure 12 Pyra-Aid™ Prototype Configuration 3 Solid Model J. Roberts

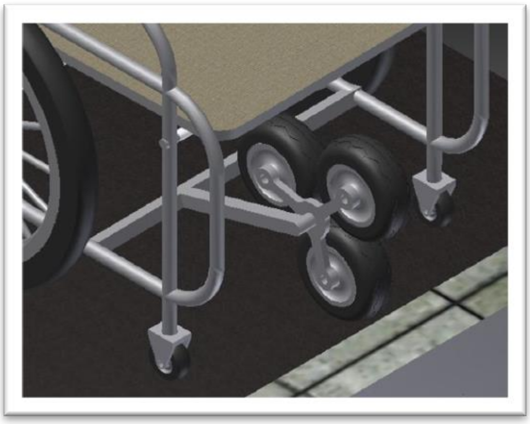

Figure 13 Pyra-Aid™ Prototype Configuration 3 Solid Model J. Roberts

4.3 Pyra-Aid™ 3 Spoke Plate Design Mark 1

Advanced computer aided design finite element and material analysis methodologies were employed by the author in the design optimisation of the Mark 1 Pyra-Aid™ 3 Spoke Mild Steel Plate and Support Structure Design. These and subsequent analyses are based on wheelchair / kerb impact of a wheelchair and 17 stone user - 1148N load case.

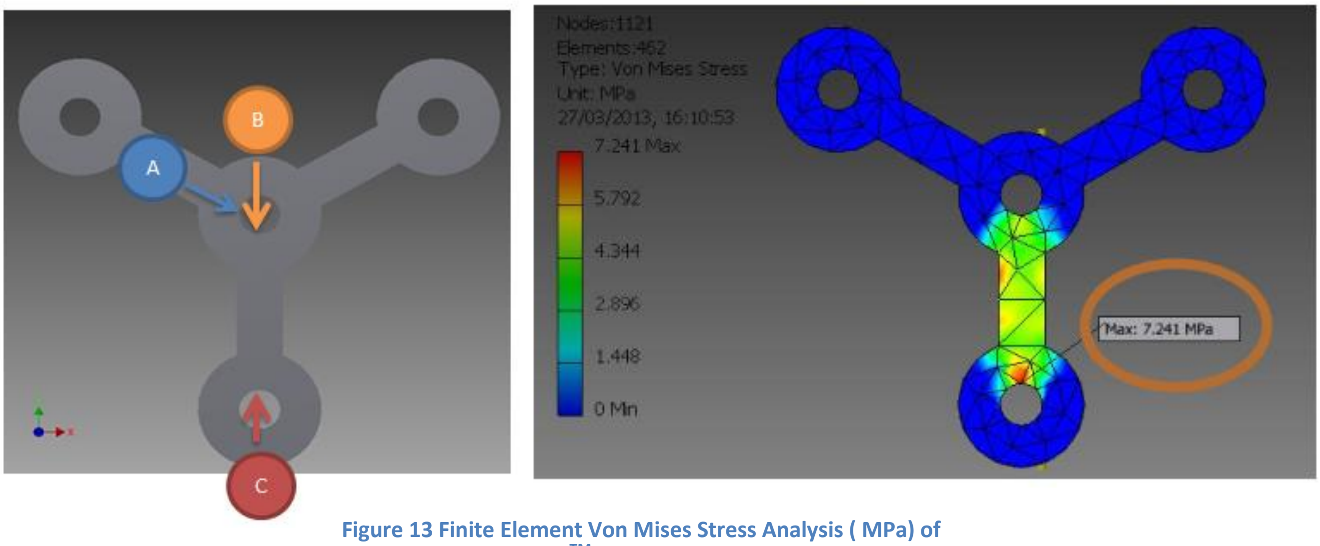

Figure 13 Finite Element Von Mises Stress Analysis (MPa) of Pyra-Aid™ 3 Spoke Plate Design J. Roberts

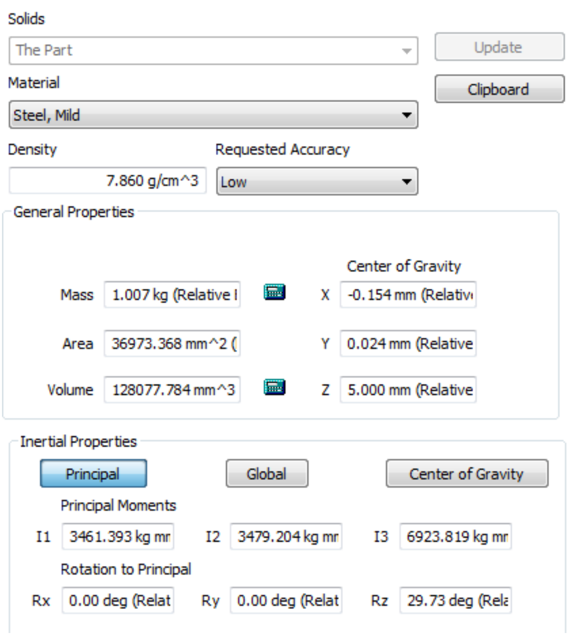

Figure 14 Material Section Property Analysis (CES Edupak) of Pyra-Aid™ 3 Spoke Plate Design J. Roberts

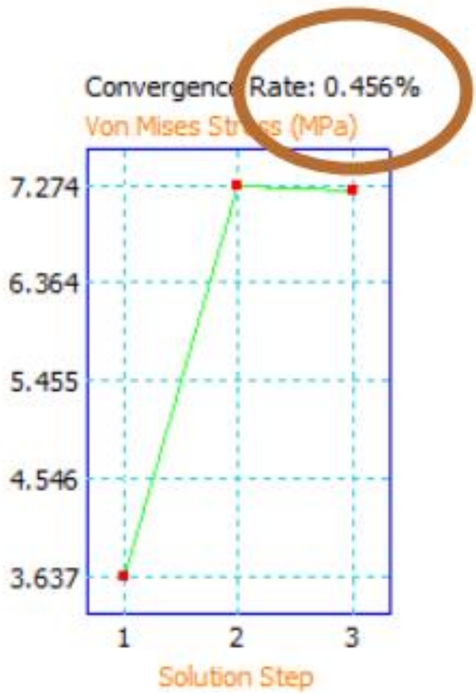

Figure 15 Convergence of Finite Element Stress Analysis of Pyra-Aid™ 3 Spoke Plate Design J. Roberts

4.4 Anti-Tipping Device Development

During the mounting of a kerb or step, the possibility of the wheelchair tipping backwards due to a shift in the centre of gravity of the chair and user increases. To address this significant safety concern, the iterative development and optimisation of an anti-tipping device was undertaken by the author. The Mark 2 developed anti-tipping device pendulum design facilitates both ease of attachment and quick and effective deployment.

Figure 16 Pyra-Aid™ Mark 1 Prototype AntI-Tipping Device Solid Model
J. Roberts

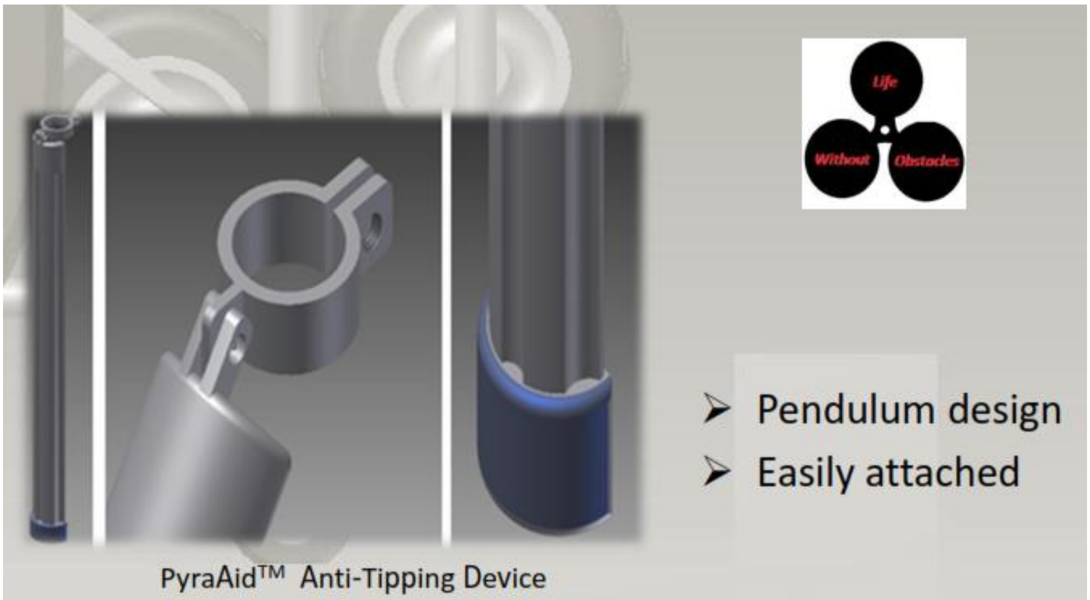

Figure 17 Pyra-Aid™ Mark 2 Prototype AntI-Tipping Device Solid Model
J. Roberts

4.5 Design for Ease of Universal Attachment / Detachment

The design for ease of attachment / detachment of the Pyra-Aid™ developing device is of critical importance to the operation of the mechanism and commercial success of the product. Advanced structural analysis techniques, including the development of finite element stress/displacement mechanism models, have been employed to optimise the operational efficiency of the novel attachment device. The adjustable design feature of the Mark 2 Pyra-Aid™ attachment device enhances the brand universality of the Pyra-Aid™ product.

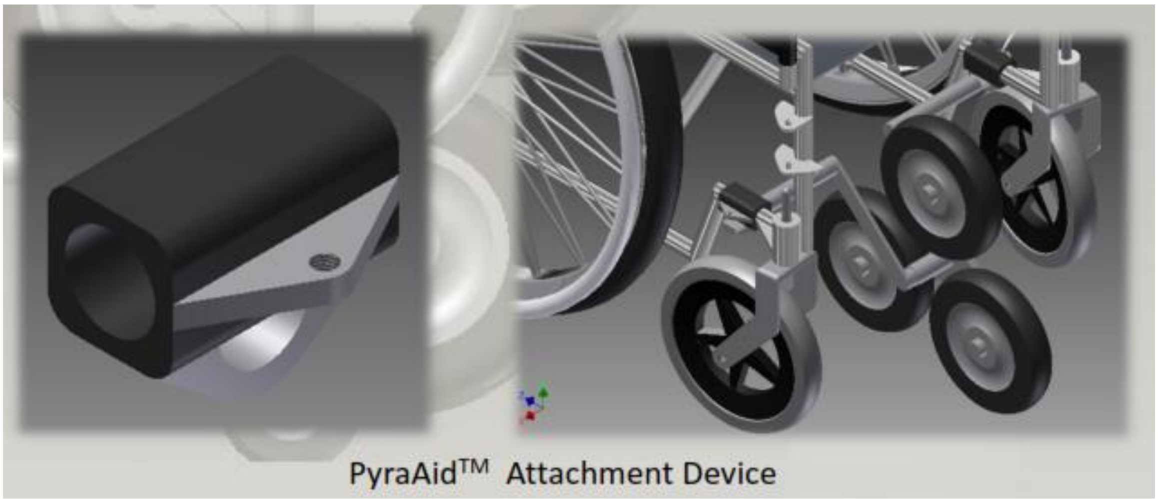

Figure 18 Pyra-Aid™ Prototype Attachment Device Mark 1 Solid Model
J. Roberts

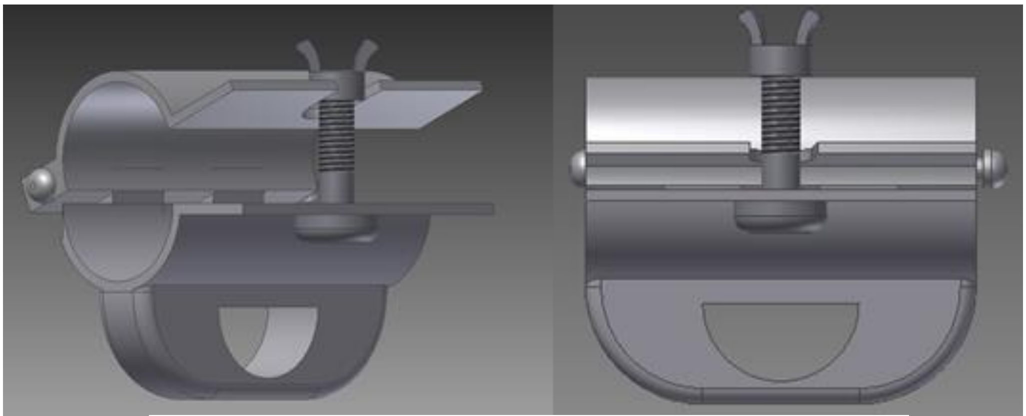

Figure 19 Pyra-Aid™ Prototype Attachment Device Mark 2 Solid Model
J. Roberts

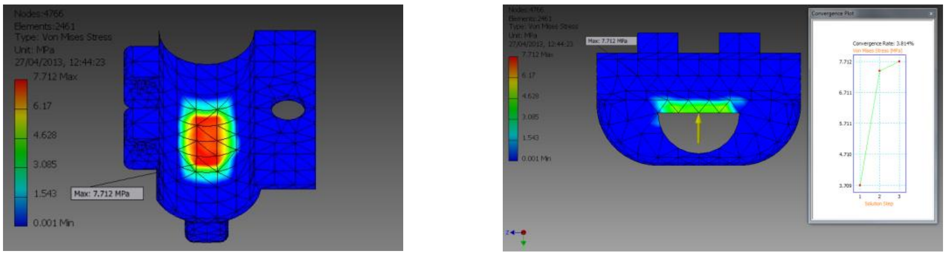

Figure 20 Pyra-Aid™ Finite Element Stress (MPa) Analysis of Prototype Attachment Device Mark 2
J. Roberts

4.6 Pyra-Aid™ Mark 1 Prototype Manufacture

The manufacture and assembly of the Pyra-Aid™ Mark 1 Prototype 3 Spoke Plate configuration, support structure, attachment mechanism and tri-wheel system was undertaken. The assembled device was attached to a general use popular brand foldable wheelchair , donated most kindly by the University Hospital – a most valued and enthusiastic supporter of the project and product.

Figure 21 Manufactured Pyra-Aid™ Prototype Mark 1

Figure 22 Donated Foldable Wheelchair – Cork University Hospital

5. Pyra-Aid™ Mark 1 Prototype Field Testing and Redesign

Field Testing of the Mark 1 Pyra-Aid™ Prototype was undertaken on kerbs of varying heights. For safety reasons, all field tests were carried out with the author as wheelchair user. The developed prototype showed significant improvement in effectiveness in mounting kerbs as opposed to unassisted wheelchairs – see Section 9 for details of these field test results.

Figure 23 Pyra-Aid™ Mark 1 Prototype Field Testing

A number of significant issues arose during the field testing of the device. One such issue comprised of kerb mounting failure due to castor wheel obstruction.

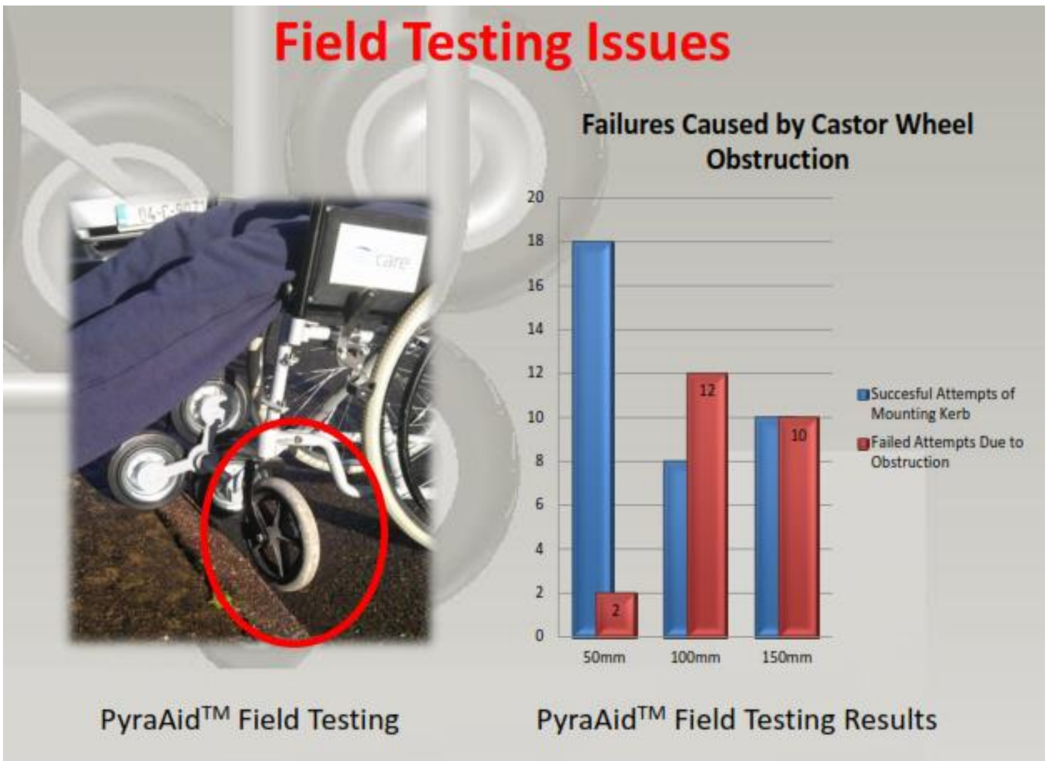

Figure 24 Pyra-Aid™ Mark 1 Prototype Field Testing
Castor Wheel Obstruction Failure

The author undertook the development and optimisation of a castor wheel alignment system . Mark 1 alignment prototype was designed based on a spring loaded knob and notch mechanism. Mark 2 prototype system comprised a universal, easily attached, low cost progression.

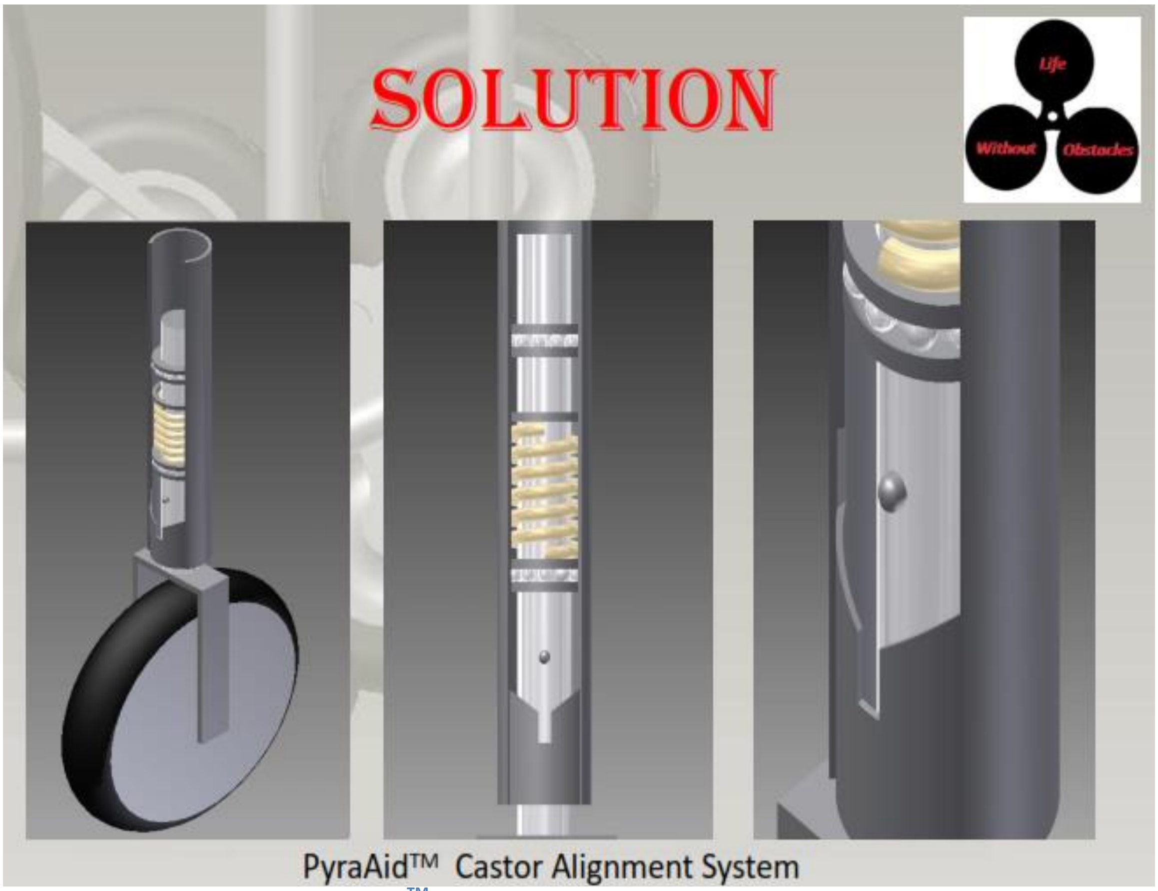

Figure 25 Pyra-Aid™ Castor Alignment System Mark 1 Prototype Solid Model
J. Roberts

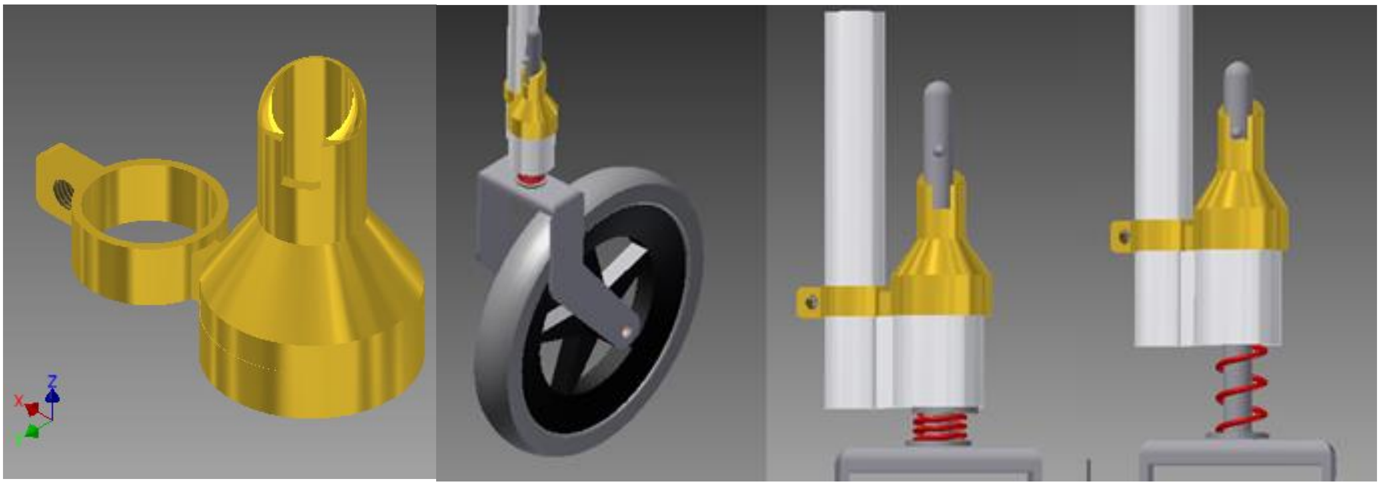

Figure 26 Pyra-Aid™ Low Cost Castor Alignment System Mark 2 Prototype Solid Model
J. Roberts

Another significant field test issue arose due to castor wheel rotation restriction due to the Pyra-Aid^{TM} support structure. The implemented solution comprised a step support structure from spoke plate to side rail.

Figure 27 Pyra-Aid^{TM} Mark 1 Prototype Field Testing
Castor Wheel Rotation Restriction

Figure 28 Pyra-Aid^{TM} Mark 1 Prototype
Redesigned Step Structure Support System Solid Model
J. Roberts

The shape optimisation of the implemented step structure solution to the castor wheel rotation restriction issue was aided by the development of finite element stress and displacement models.

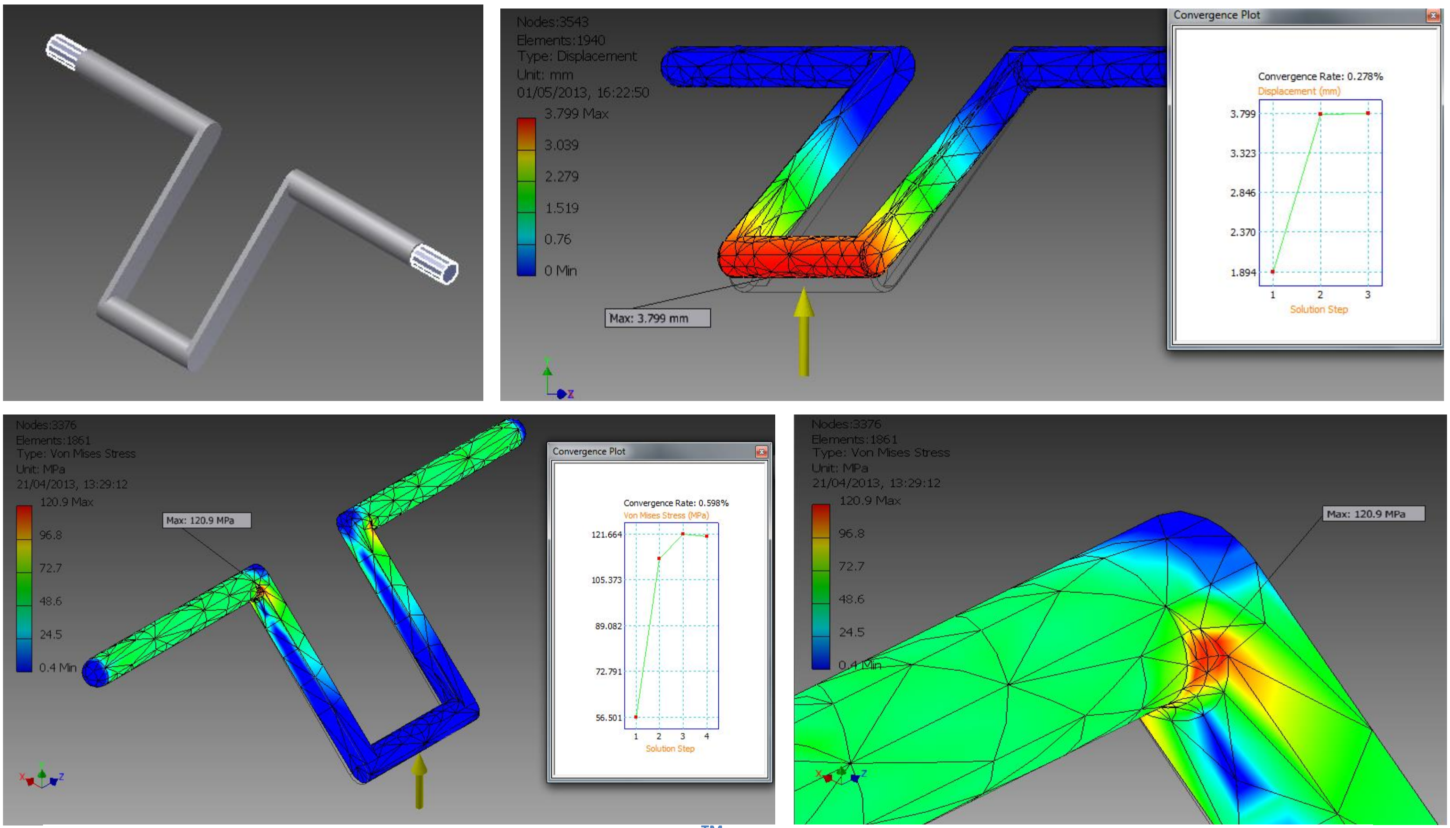

Figure 29 Pyra-Aid™ Mark 1 Prototype
Redesigned Step Structure Support System
Finite Element Stress (MPa) and Displacement (mm) Models
J. Roberts

6. Development of Mark 2 Pyra-Aid™ Prototype

The requirements for solutions to the issues arising from field testing allied with the imperative to significantly reduce the mass / dimensional space of the developing kerb mounting solution led to the development of a Mark 2 Pyra-Aid™ Prototype.

Material optimisation was first addressed. Material selection is central to the manufacturing process and the effectiveness of the product. Advanced material research was undertaken on the CES Material Edu Package. Critical design parameters included mass reduction, long fatigue life and compatibility with hospital / medical environments.

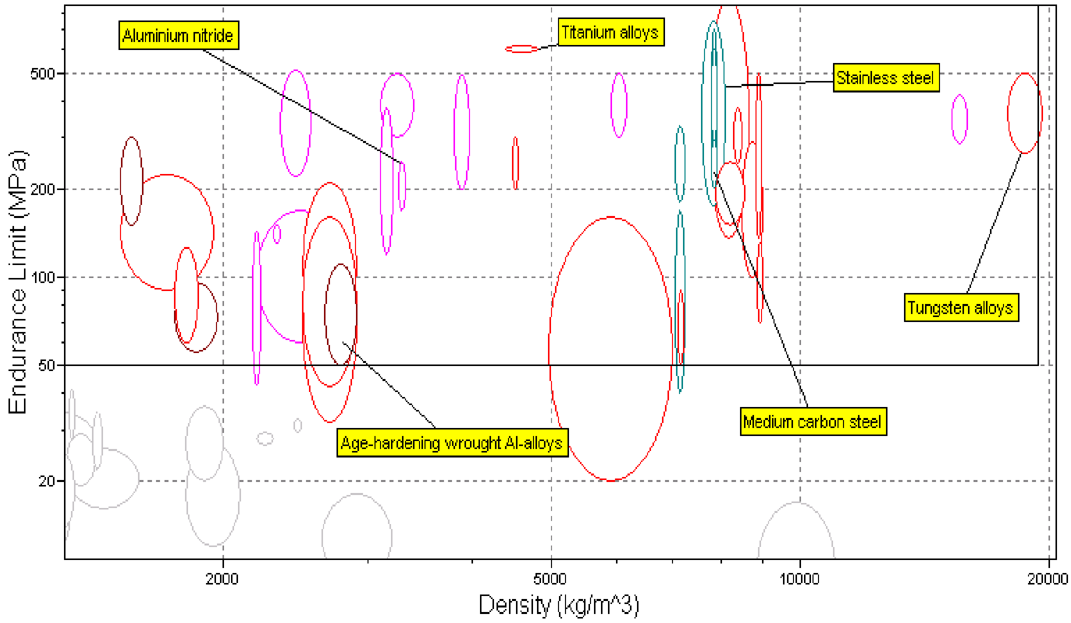

Figure 30 Pyra-Aid™ Material Optimisation – CES Edupack Database

With a high fatigue strength to weight ratio and excellent bacterial growth retarding properties [6] , Aluminium Alloy 6061 T6 was selected as the optimum material to replace mild steel in Pyra-Aid™ Prototype Mark 2.

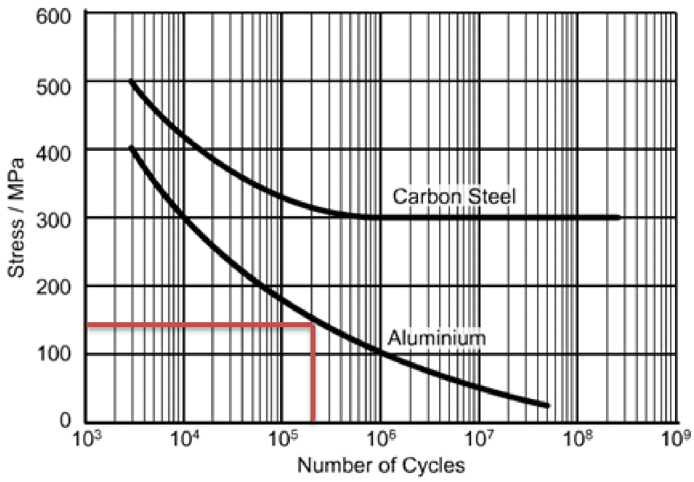

Figure 31 Determination of Fatigue Life of Pyra-Aid™ Mark 2 [24]

Fatigue life for the specified maximum allowable stress is estimated to be in excess of 27 years for the Mark 2 Aluminium Alloy Pyra-Aid™ Prototype.

Optimisation of the plate geometry was undertaken. Mark 2 Concept Design 2 and Concept Design geometries are iteratively developed from and compared with Mark 1 Concept Design 1.

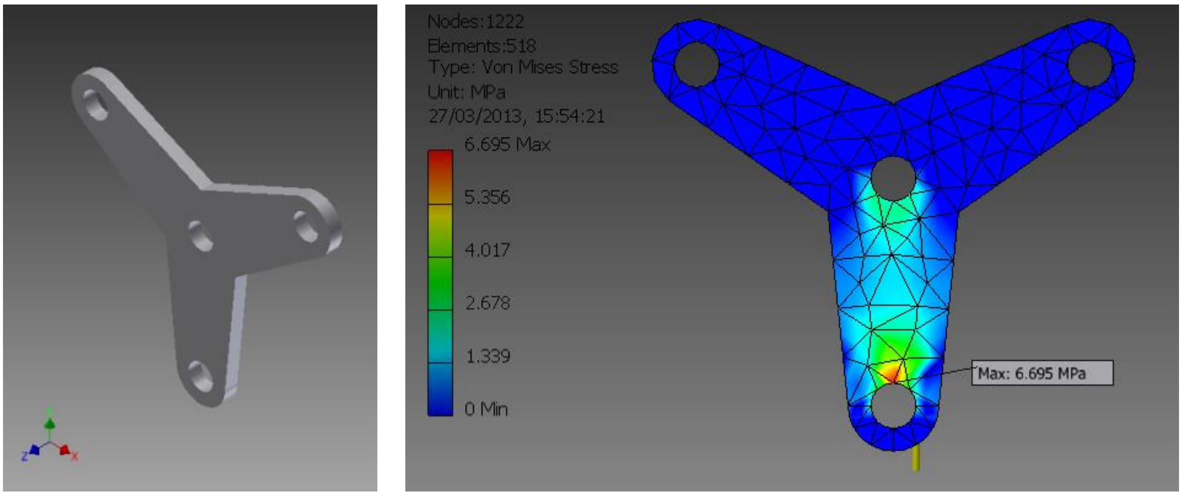

Figure 33 **Pyra-Aid™ Concept Design 2 Plate - Von Mises Stress Analysis (MPa) - Aluminium J. Roberts**

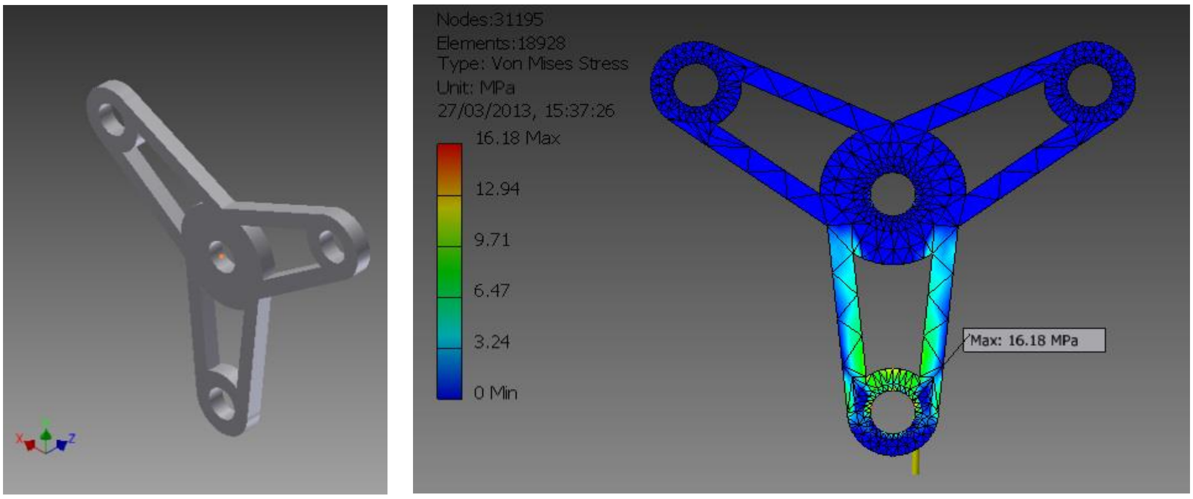

Figure 33 **Pyra-Aid™ Concept Design 3 Plate - Von Mises Stress Analysis (MPa) - Aluminium J. Roberts**

Design	Mass (kg)	Max Von Mises Stress (MPa)	Allowable Stress for FOS of 2 (MPa)	*Ease of machining
Original (mild Steel)	1.007	7.241	138	Manual Time consuming
Original (Aluminium)	.347	7.2	138	Average
Option 2	.382	6.695	138	Very Good
Option 3	.098	16.18	138	Average

Ease of machining assessment is based on information gathered from experienced machining technicians

Figure 34 **Pyra-Aid™ Concept Design 3 Plate – Aluminium J. Roberts**

All investigated plate design concept options were well below the allowable stress limits for required fatigue life. Design option 3 requires some additional machining over the other investigated options, but is by far the lowest mass and was thus selected for further investigation analysis and optimisation.

Iterative and exhaustive 3D finite element stress analyses - load cases simulating applied loads on the Pyra-Aid™ Prototype during kerb mounting cycle were undertaken on progressive configurations of design option 3.

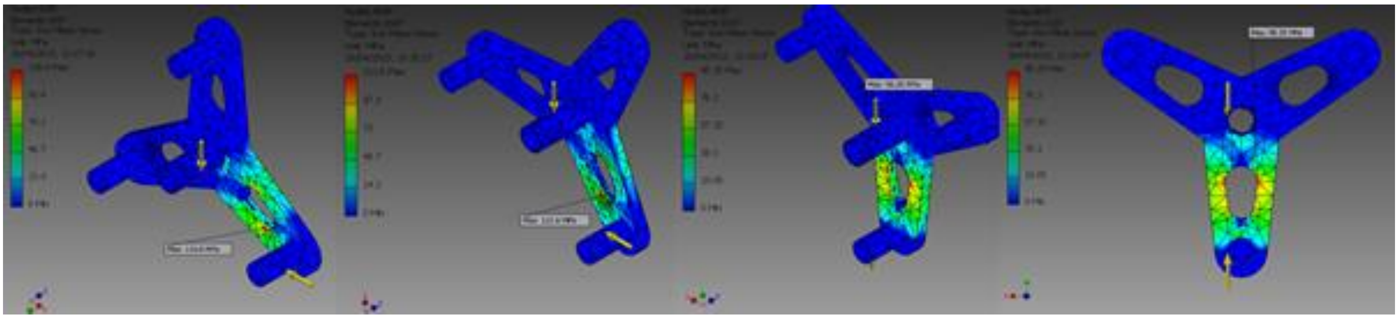

Figure 35 Pyra-Aid™ Concept Design 3 Plate - 3D Analysis Stress Analysis (MPa) - Kerb Mounting Load Cycle Simulation J. Roberts

The optimised shape and configuration was selected as the basis for the plate, axle, support and attachment structure solid model assembly of the Mark 2 Pyra-Aid™ Prototype:

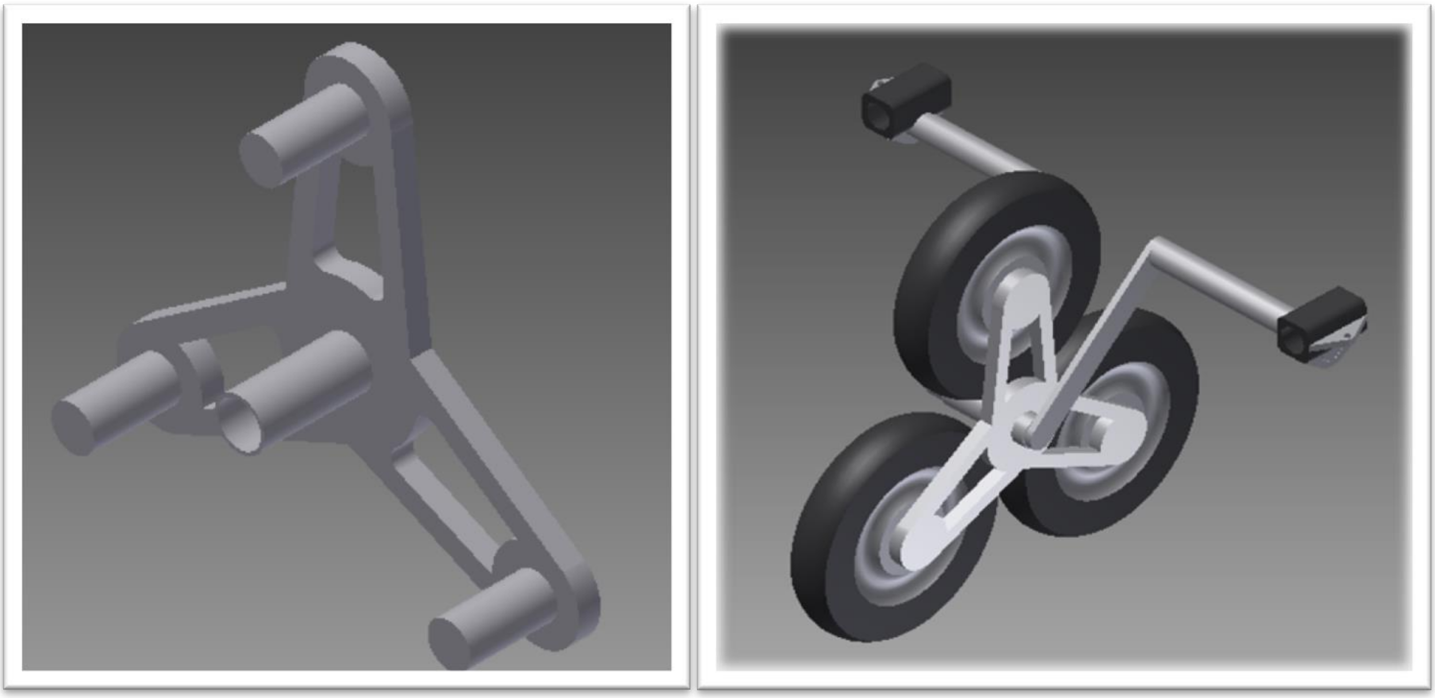

Figure 36 Pyra-Aid™ Optimised Concept Design 3 Plate Configuration and Solid Model Assembly J. Roberts

The incorporation of the developed Mark 2 Pyra-Aid™ Prototype assembly into the wheelchair structure was undertaken.

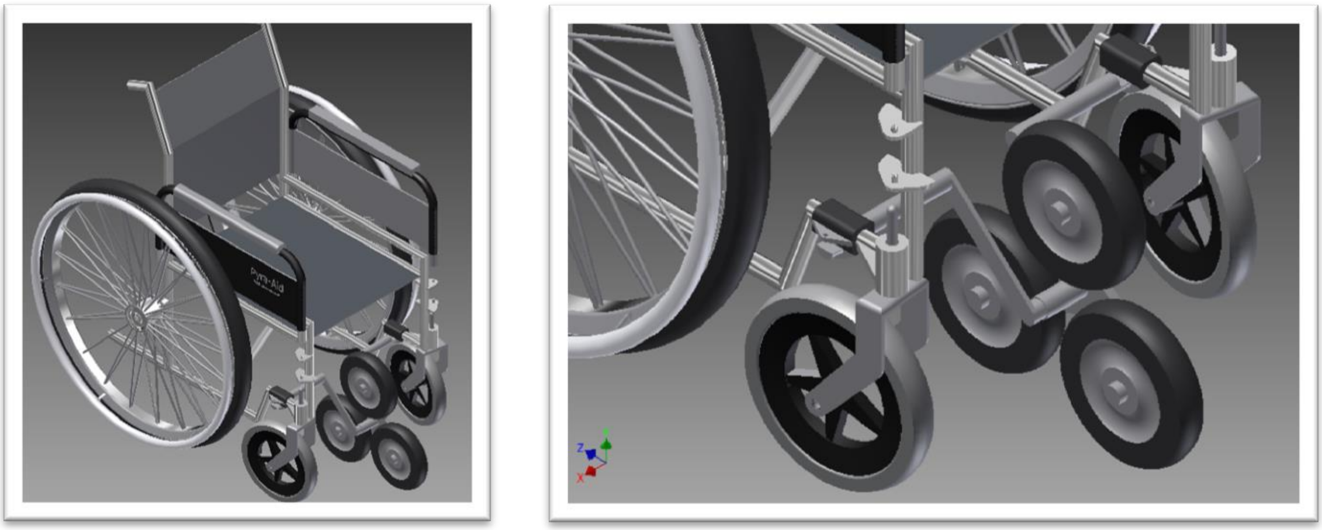

Figure 37 Mark 2 Pyra-Aid™ Prototype attached to Wheelchair Structure J. Roberts

The manufacture from design and assembly of the Mark 2 Pyra-Aid™ Prototype was progressed.

Figure 38
Manufactured and Assembled Mark 2 Pyra-Aid™ Prototype
J. Roberts

Field Testing of the Mark 2 Pyra-Aid™ Prototype was then undertaken. The details and results of this testing are presented in Section 9.
For safety reasons, all field tests were carried out with the author as wheelchair user.

7. Development of Mark 3 Pyra-Aid™ Prototype

The author decided to undertake the development of a Mark 3 Prototype based on significantly smaller diameter wheels with the primary aim of achieving a lighter more aesthetically pleasing product with less space constraints. The smaller wheels however imposed a major design constraint - a significant reduction in diameter of the prototype wheel axles to 8mm outer diameter.

Figure 39 Mark 2 Pyra-Aid™ Prototype Wheel
152mm Outer Diameter

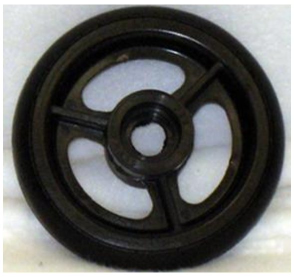

Figure 40
Mark 3 Pyra-Aid™ Prototype Wheel
102mm Outer Diameter

The initial approach by the author was to develop a scaled down version of the Mark 2 prototype model.

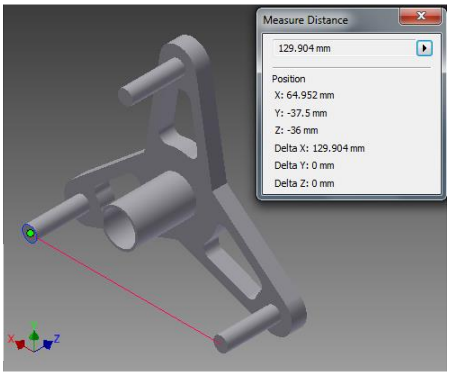

Figure 41
Mark 3 Pyra-Aid™ Prototype Wheel
Scaled 3D Solid Model
J. Roberts

The author undertook extensive finite element analysis and optimisation of the developed scaled solid model.

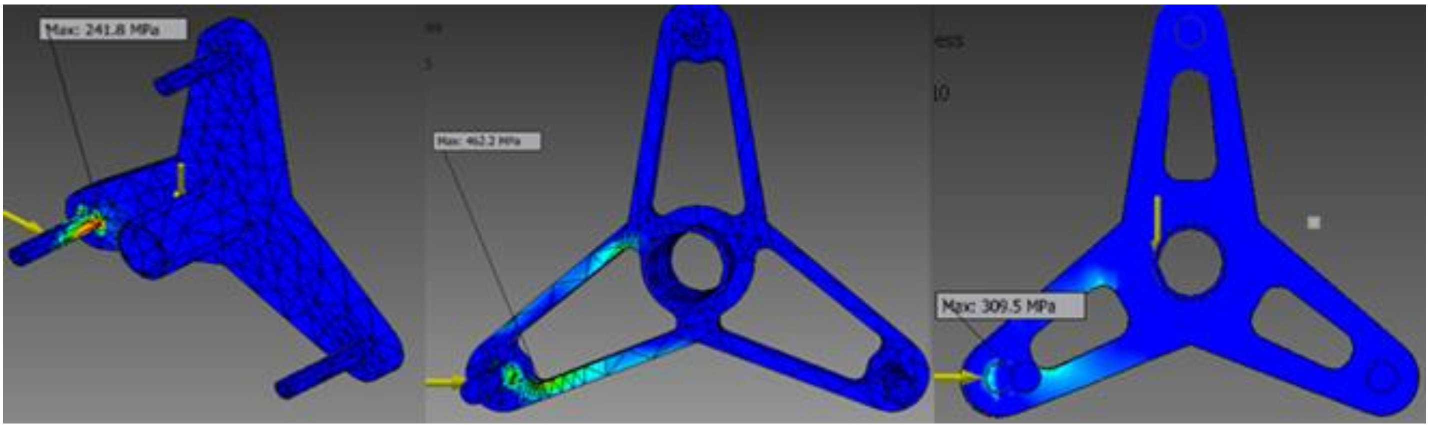

Figure 42
Pyra-Aid™ Mark3 Prototype Scaled Concept Design
3D Stress Analysis (MPa) - Kerb Mounting Load Cycle Simulation
J. Roberts

Design	Max Stress(MPa)	Location	Life Cycle
Scaled Mark 2 model	310	Stem of Axle	1.2 Years
Material Removed	462	Edge of Material	FAIL
No Material Removed	242	Stem of Axle	3.8 years

Figure 43 Maximum Stress Locations
Pyra-Aid™ Mark3 Prototype Scaled Concept Design
3D Analysis - Kerb Mounting Load Cycle Simulation
J. Roberts

The finite element analyses indicate maximum stresses outside the allowable fatigue life limits in all investigated configurations for the scaled down model.

A dual plate configuration was devised by the author as a mechanism of reducing stress to allowable limits.

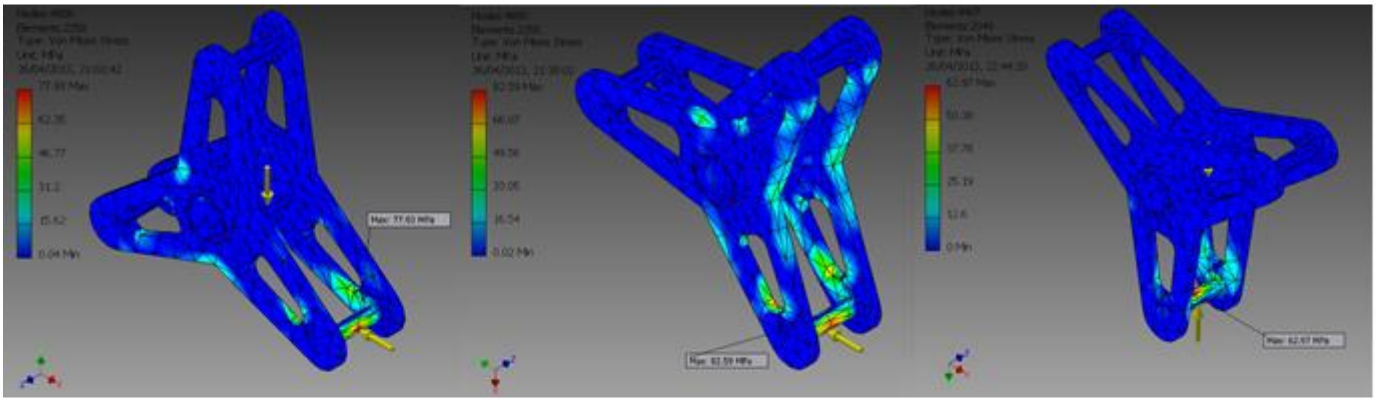

Figure 44
Pyra-Aid™ Mark3 Prototype Dual Plate Concept Design
3D Stress Analysis (MPa) - Kerb Mounting Load Cycle Simulation
J. Roberts

Various plate widths were investigated as to optimality in stress distribution – the optimum distribution achieved by two 5mm plates - balancing mass reduction with the single 10mm scaled down plate width.

Model	Direction of Load A(kerb Impact)	Direction of Load B (user Load)	Max Von Mises (MPa)	Max 1st Principal (MPa)	Max 3rd Principal (MPa)
10mm Double Plate	-Y	-X	49.74	47.75	-55
	-X	-Y	53.9	54.65	-56.24
	-Y	Y	41.2	38.04	-87.92
5mm Double Plate	-Y	-X	77.93	78.81	-82.87
	-X	-Y	82.59	82.91	-87.32
	-Y	Y	62.97	63.54	-65.83
3mm Double Plate	-Y	-X	94.8	95.65	-96.18
	-X	-Y	930.7	127.1	NA
	-Y	Y	NA	NA	NA

Figure 45 Pyra-Aid™ Mark3 Prototype Dual Plate Concept Design
Comparative Stress Analysis (MPa) of Diverse Plate Widths (mm)
J. Roberts

As the dual plate was deemed the optimal solution and was within fatigue life limits, the optimised shape and configuration was selected as the basis for the plate, axle, support and attachment structure solid model assembly of the Mark 3 Pyra-Aid™ Prototype:

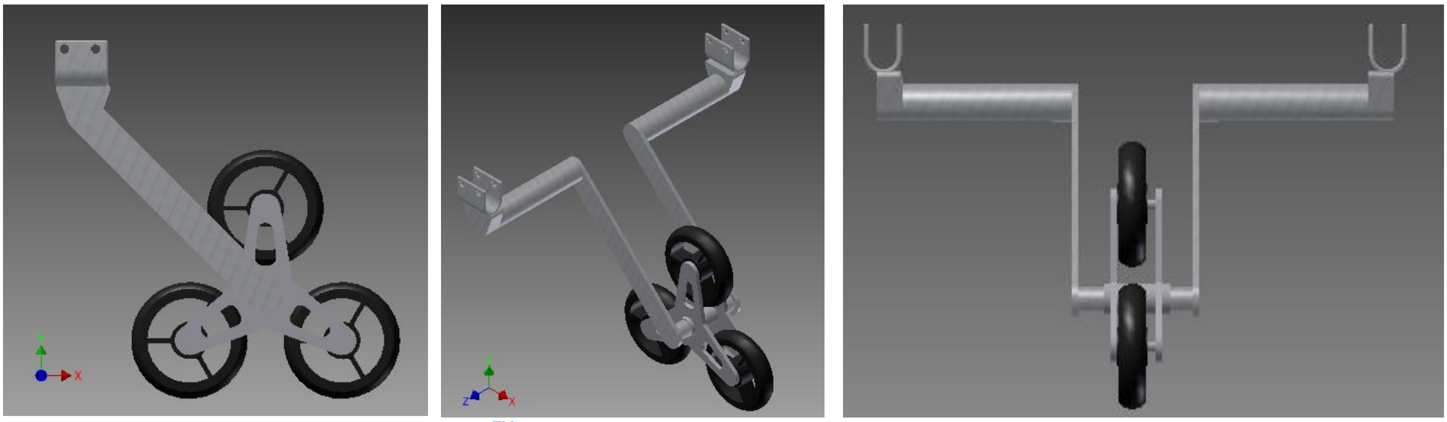

Figure 46 Pyra-Aid™ Mark 3 Dual Plate Configuration and Solid Model Assembly J. Roberts

The incorporation of the developed Mark 3 Pyra-Aid™ Prototype assembly into the wheelchair structure was undertaken. The manufacture from design and assembly of the Mark 3 Pyra-Aid™ Prototype was progressed.

Figure 47
Manufactured and Assembled Mark 3 Pyra-Aid™ Prototype
J. Roberts

Laboratory and Operational Testing of the Mark 3 Pyra-Aid™ Prototype was then undertaken.

The details and results of this testing are presented in Sections 8 and 9.

8. Photoelastic Experimental Validation

As extensive use was made by the author of finite element stress analyses in iterative prototype design progression, it was felt that experimental validation of the developed finite element stress models was appropriate. Review and assessment of experimental stress / strain methodologies was undertaken - leading to the conclusion that the most suitable method was via photoelastic techniques.

The photoelastic method enables the development of a full field experimental solution - thereby allowing determination and full field vision of locations of major stress concentration.

This full field capability is in contrast to more popular (and easier to apply) techniques such as strain gauge or deflection dial gauge measurement, which yield experimental solutions at predefined locations.

The photoelastic experimental solution is particularly compatible with finite element analytical solution, employed by the author extensively in design optimisation of the developing device, both yielding full field stress solutions.

The successful application of the photoelastic method is however a difficult process and not for the faint hearted.

Figure 48 College Terco Polariscope

Both calibration test pieces and structural models must be CNC machined from birefringent material.

Machining parameters must be carefully devised and controlled to avoid chipping and introduction of stress raisers. The heat generated by the heavy machining must be dissipated by adequate cooling to avoid boundary birefringence. Load application rigs must be designed and manufactured to apply the load and restraints in a realistic manner, while at the same time not obstructing the passage of the circular polarised light through the loaded models.

All of these requirements posed significant challenges for the realistic application of the kerb mounting complex loading cycle of the developing Pyra-Aid™ solution. The author was of the opinion that the full field experimental validation benefits were sufficiently great to endeavour to undertake the task of addressing these challenges.

All photoelastic structural models and calibration test pieces were machined from PSM-1 polycarbonate sheet material via CNC code generated by the author.

Figure 49 College Hurco BMC 20 CNC Mill

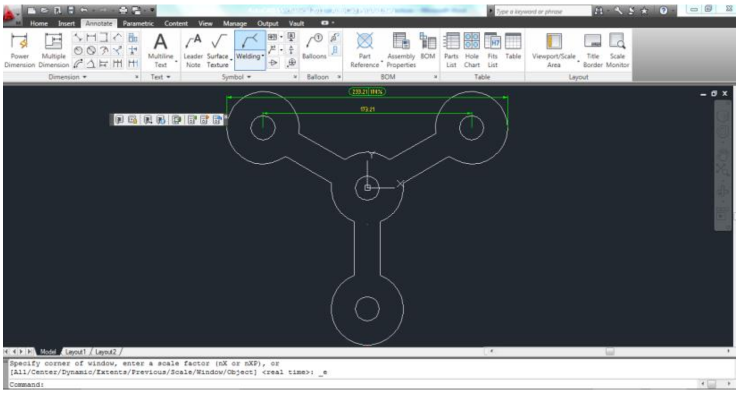

Figure 50 CNC Code Generation Model J. Roberts

The machining of calibration test pieces - used in experimentally determining the sensitivity of the PSM1 material - was first undertaken. The next step - the carefully controlled machining of the phototelastic structural models of Mark 1 and Mark 2 /3 Pyra-Aid™ prototyped configurations went very well (Figure 51) – the manufactured birefringent models exhibiting no residual stresses from the machining process.

Figure 51 Mark 1 and Mark 2 /3 Photoelastic Structural Models CNC Machined from Sheet PSM-1 Polycarbonate J. Roberts

The next step and most difficult challenge was the development of an experimental loading rig to simulate the kerb mounting load cycle. This variable load configuration requirement was achieved by the iterative solid model development and manufacture of a bolt adjustable model mounting frame.

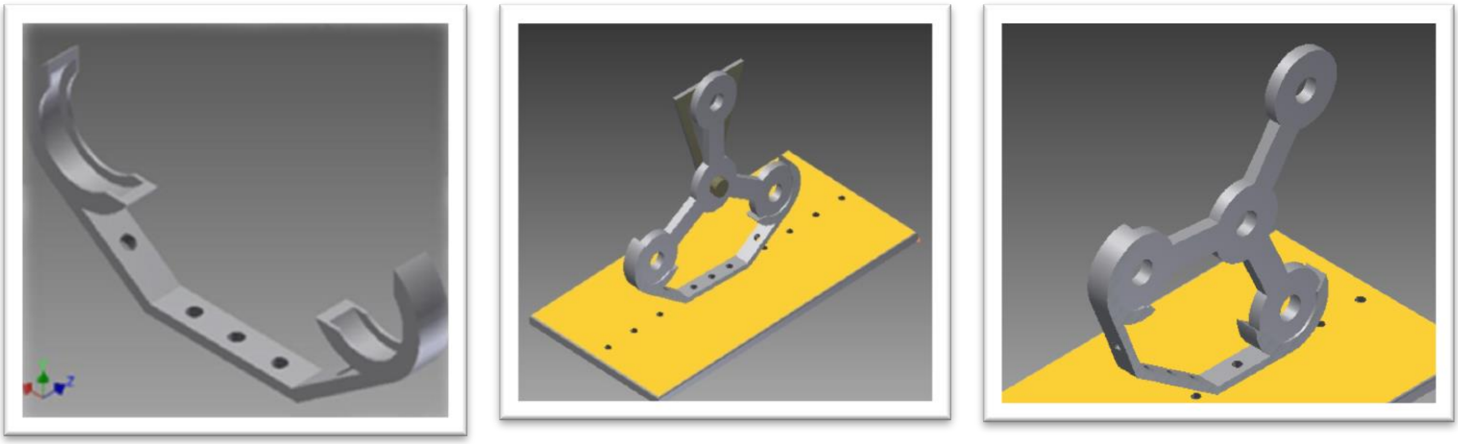

Figure 52 Concept 1 Variable Load Configuration Model Mounting Frame Solid Models
J. Roberts

Concept 1 Variable Load Configuration Model Mounting Frame was redesigned as the boundary restraint on the external diameter was deemed unrealistic.

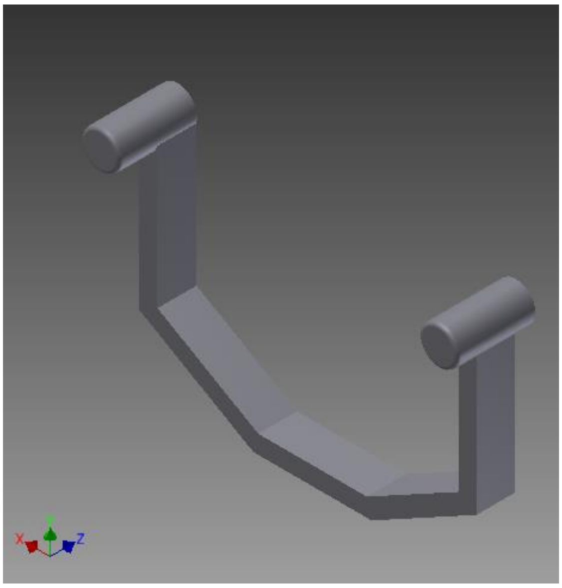

Figure 53
Concept 2 Variable Load Configuration Solid Model
Model Mounting Frame
J. Roberts

Figure 54
Manufactured Variable Load Configuration
Model Mounting Frame
J. Roberts

Concept 2 overcomes this boundary condition concern - also retaining the variable load configuration capability in the manufactured load rig.

Photoelastic experimental validation commenced.

The photoelastic sensitivity of the PSM-1 material was determined via the manufactured calibration testpieces.

The developed loading rig and manufactured phototelastic structural models of Mark 1 and Mark 2 /3 Pyra-Aid™ prototyped configurations were subjected to photoelastic testing via the Terco polariscope:

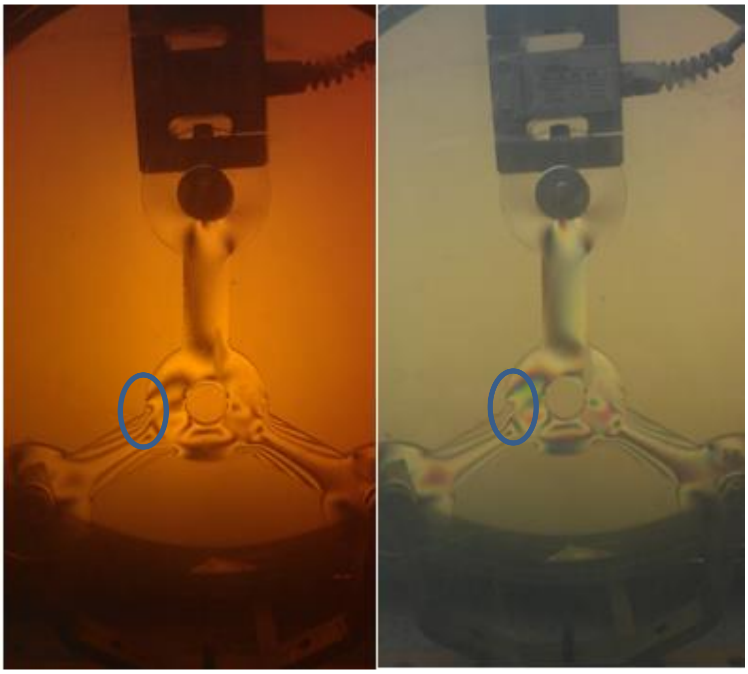

Figure 55 Photoelastic Experimental Full Field Stress Measurement
Mark 1 Pyra-Aid™ Prototype
Sodium and White Light Sources
J. Roberts

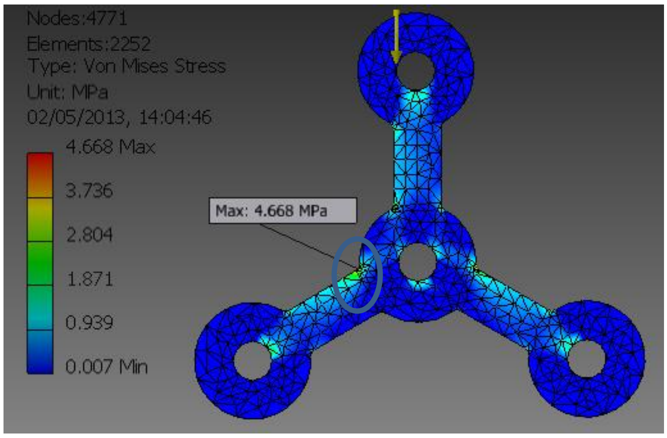

Figure 56 Finite Element Full Field Stress Analysis (MPa)
Mark 1 Pyra-Aid™ Prototype
J. Roberts

Load Applied N	Fringes	MPa Max Stress (Fringes x Material Sensitivity)	MPa Max Stress of Polycarbonate Using FEA	% Correlation
10.9	1	1.0885	.7297	67
26.6	2	2.177	1.831	84
50.8	3	3.266	3.497	93
68	4	4.354	4.668	93
85.8	5	5.4425	5.907	92

Figure 57 Tabular Comparison of Photoelastic and Finite Element Maximum Stresses (MPa)
Mark 1 Pyra-Aid™ Prototype J. Roberts

Close correlation - in excess of 90% at the higher and more realistic load levels - may be observed in the location (circled in Figures 53 and 54) of maximum stress concentration in the photoelastic and finite element models.

This full field correlation is hugely encouraging as to the validity of the developed finite element solutions to realistically model the boundary conditions of the Pyra-Aid™ kerb mounting complex load cycle.

Comparison of the maximum stress magnitudes shows a higher correlation in the critical higher load applied levels - a further most encouraging correlation between experimental and finite element models. % differences increase for lower load levels - this is to be expected as sensitivity effects increase at low load levels.

Similarly very good correlations between locations and magnitudes of stress concentrations are also observed in the Mark 2/3 experimental photoelastic and analytical finite element results.

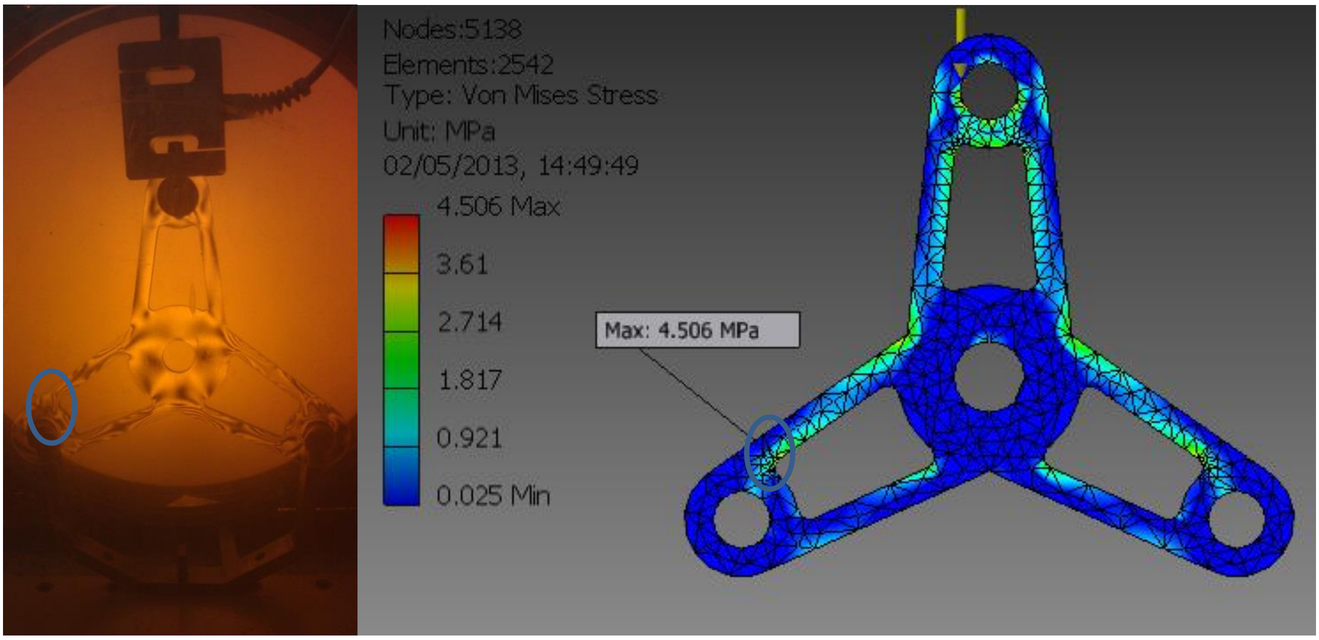

Figure 58 Photoelastic and Finite Element Full Field Stress Models (MPa)
Mark 2/3 Pyra-Aid™ Prototype
J. Roberts

The observed and measured correlation between experimental photoelastic and finite element models maximum stress concentration locations and magnitudes in Mark 1, 2 and 3 models inspires confidence in the application of advanced computer based analytical techniques in advancing the design optimisation and iterative efficient prototype production of the developing product.

See Video of Development / Testing on: ***http://www.youtube.com/watch?v=9D_J80lWfcY***

9. Field Testing of Pyra-Aid™ Prototypes

Mark 1 Pyra-Aid™ Prototype Field Testing

Extensive Controlled Environment Field testing of the Mark 1 Pyra-Aid™ Prototype was carried out on various heights of kerbs from 30mm to 160mm. Field test results are presented in diagrammatic form in Figure 59. See Video of Development / Testing on http://www.youtube.com/watch?v=cg1HSksEs2s

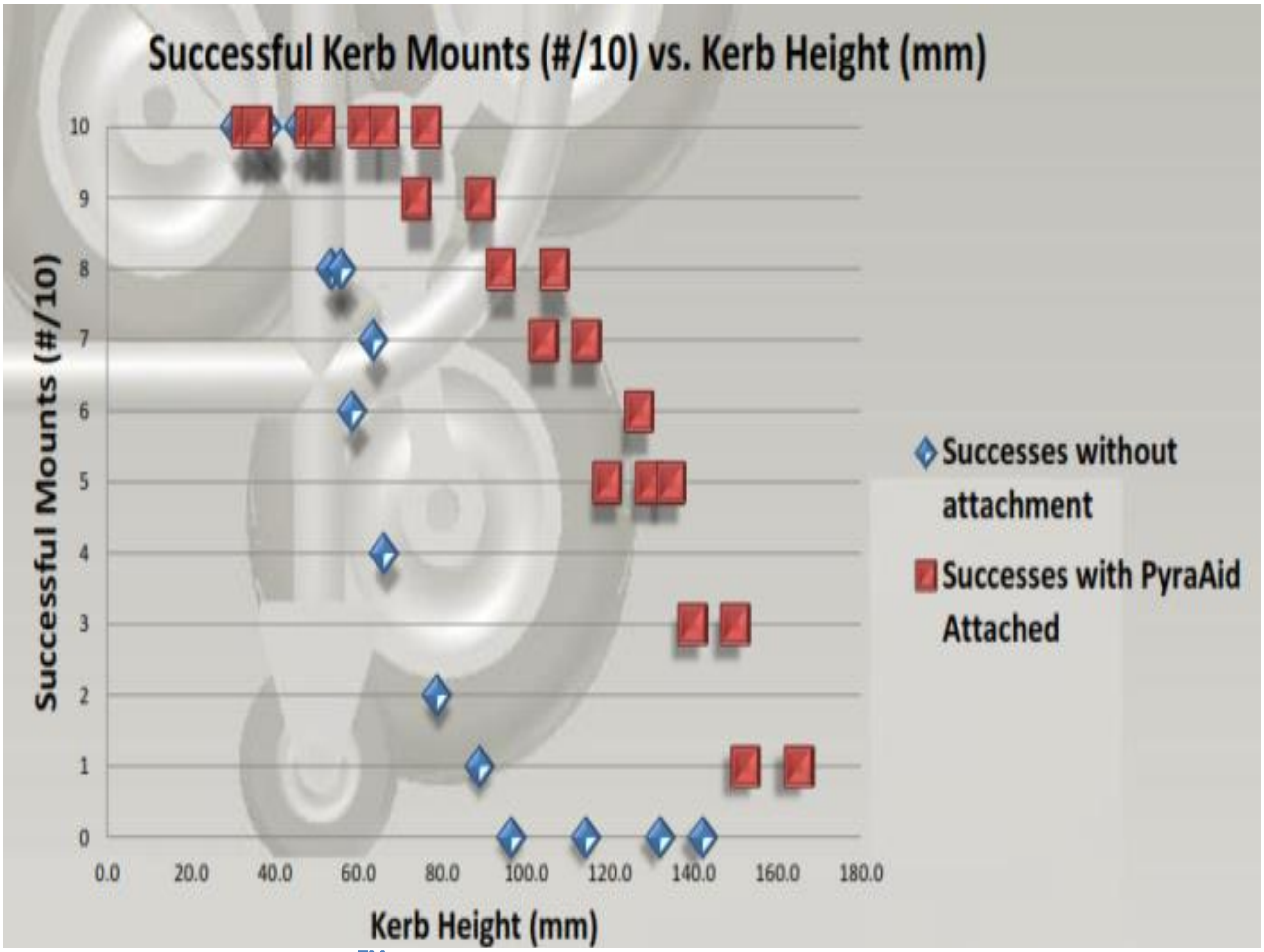

Figure 59 PyraAid™ Prototype Mark 1 Controlled Environment Field Testing
All Field Tests carried out with Author as Wheelchair User

A significant enhancement of the wheelchair user's ability may be observed from 50mm to 130mm kerb heights.

The wheelchair user, when not attached to the Mark 1 Pyra-Aid™ Prototype, failed at all attempts on kerbs of 100mm height or above – but experienced considerable success when attached to the Mark 1 Pyra-Aid™ Prototype.

These results were very encouraging in progressing Pyra-Aid™ to wider environment field testing and Mark 2 / 3 prototypes.

Mark 2 Pyra-Aid™ Prototype Field Testing Results

Kerb Height(mm)	Attempts	Success		% Success
		Castors	Back wheels	
30	5	5	5	100
50	10	9	8	90
80	15	12	4	80
100	15	7	X	47
130	15	8	X	53
160	15	7	X	47

Figure 60 Mark 2 Pyra-Aid™ Prototype Field Testing

Mark 3 Pyra-Aid™ Prototype Testing Results

Kerb Height(mm)	Attempts	Success		% Success
		Castors	Back wheels	
0-30	5	5	5	100
31-50	15	13	10	86
51-80	15	13	4	86
81-100	15	9	X	60
101-130	15	4	X	26
131-160	10	2	X	20

Figure 61 Mark 3 Pyra-Aid™ Prototype Field Testing

Performance Comparisons

Kerb Height(mm)	Mark 1/2 % Success Rate	Mark 3 % Success Rate
0-30	100	100
31-50	90	86
51-80	80	86
81-100	47	60
101-130	53	26
131-160	47	20

Figure 62 Pyra-Aid™ Prototype Performance Comparisons

The performance comparison of Figure 62 clearly points to progress made regarding the mounting of kerbs at moderate heights from 50mm to 100mm with a major decline in Mark 3 ability to mount the higher kerb heights from 130mm to 160mm. This decline is ascribed to the implemented reduction in wheel diameters. Interestingly, however, Mark 3 is more effective in the range 50mm to 100mm. Mark 1/2 and Mark 3 prototypes are equally as effective for kerbs below 50mm.

10. Mass and Cost Comparison of Prototypes

A comparison of the mass distribution in the three developed and manufactured prototypes is undertaken and is presented in diagrammatic and tabular form in Figures 63 and 64. A pictorial comparison is presented in Figure 65.

Prototype	Total Mass(Kg)	Total Wheel Mass(Kg)	Plate Mass(Kg)	Holder Mass(Kg)	Percentage Improvement
Mark 1	4.98	3.18	1.2	.6	-
Mark 2	4.081	3.18	.438	.463	18%
Mark 3	1.092	.144	.456	.492	78%

Figure 63 Pyra-Aid™ Prototype Mass Distribution Tabular Comparison

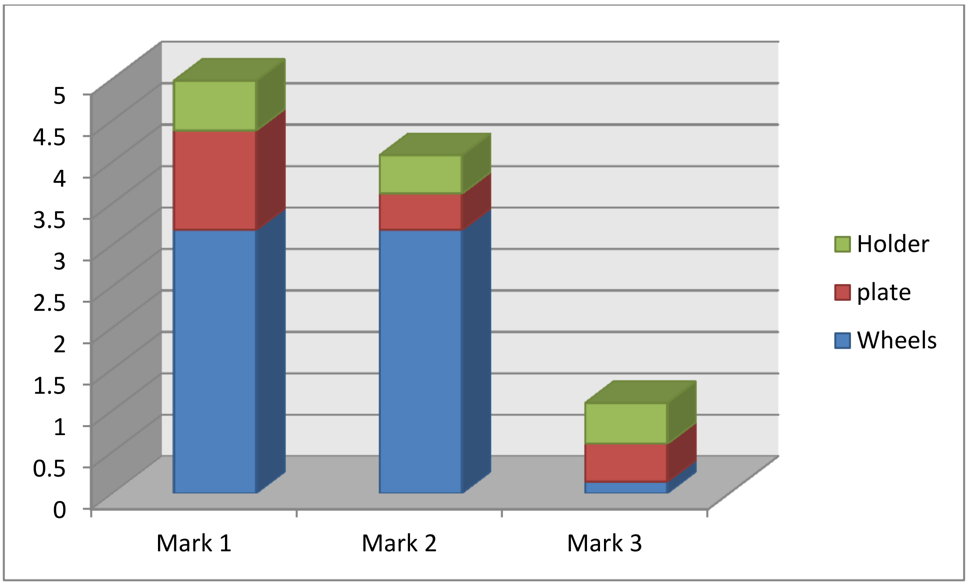

Figure 64 Pyra-Aid™ Prototype Mass Distribution Tabular Comparison

Figure 65 Pictorial Comparison of Pyra-Aid™ Prototype Mark 2 and 3

The comparison clearly points to a very significant reduction in mass by 78% from prototype 1 to prototype 3 (Figure 63).

The greatly reduced mass of the Mark 3 prototype is highly desirable from the wheelchair user's perspective – adding as little weight as possible to the wheelchair.

The smaller size and reduced space requirements of the Mark 3 prototype also add to the aesthetic attractiveness of the product (Figure 65).

The reduced mass of the Mark 3 prototype contributes to an enhanced performance for low and moderate kerb sizes, but this is balanced by a significant reduction in performance at high kerb sizes (Figure 62) - ascribed to the implemented smaller wheel diameter (152mm diameter reduced to 102mm diameter).

A detailed materials and labour breakdown costing comparison of the three developed and manufactured prototypes is undertaken and is presented in Figure 66.

Pyra-AidTM Prototype	**Mark 1**			**Mark 2**			**Mark 3**		
	Material	Labour Hrs		Material	Labour Hrs		Material	Labour Hrs	
		Machining	fabricating		Machining	Welding		Machining	Welding
Wheels x 3	€ 37.50			€ 37.50			€ 78.00		
3 spoke plate	€ 5.00	1.5	0.5	€ 11.50	2	1	€ 20.00	3.5	1.5
Shaft	€ 8.00		2	€ 9.50		0.5	€ 9.50		0.5
Attachments				€ 12.00	2	1	€ 12.00	2	1
Labour Rate/hour		€ 28.00			€ 45.00			€ 45.00	
Sub Total	€ 50.50		€ 112.00	€ 58.50		€ 157.50	€ 107.50		€ 247.50
Total	€ 162.50			€ 216.00			€ 355.00		

Figure 66 Once Off Prototype Material and Labour Cost Comparison of Pyra-Aid™

It must be emphasised that the material and labour costs presented are based on once-off prototype production and will be significantly reduced due to economies of scale and efficiencies of mass manufacture on product production for market. The mass manufacture cost is estimated at **below €120.**

Life Without Obstacles

11. Future Work

To undertake comprehensive and sustained liaison with wheelchair user and support groups in the advancement of the Pyra-Aid™ user driven and centric device.

To undertake further extensive testing of the developing device with a broader range of subjects to include male / female and able bodied / disabled subjects with varying levels of fitness.

To investigate alternative materials such as high strength to weight ratio polymers and low cost raw materials / mass manufacturing techniques.

To undertake continuous innovation to optimise the operation of the developing device - the advanced design optimisation, development and testing of a low cost functional castor alignment device shows the potential for major operational improvement of all developed prototypes.

To investigate device innovation intellectual property protection - the developing low cost castor alignment system shows significant potential in this regard - see Figure 67.

To advance commercialisation of the product.

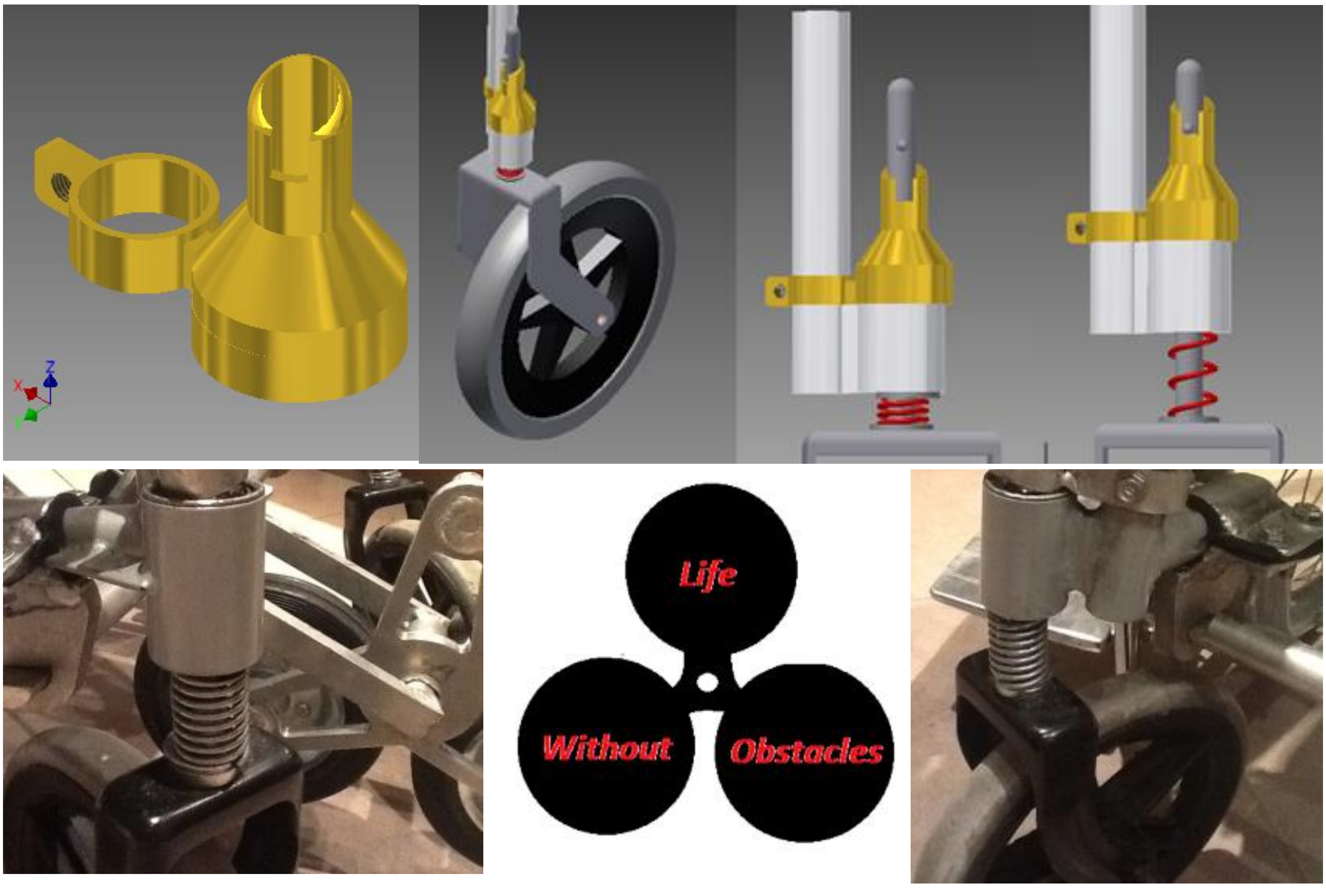

Figure 67 Pyra-Aid™ Low Cost Castor Alignment System Initial Concept Design and Mark 1 Prototype Manufacture
J. Roberts

See Video of PyraAid™ Development / Testing on: http://www.youtube.com/watch?v=9D_J80lWfcY

12. Conclusion

The progressive design optimisation, development and testing of Pyra-Aid™, a retro fitted, user friendly, momentum powered mechanical device to aid in mounting of single steps or kerbs, has been successfully undertaken.

A systematic design approach, informed by wheelchair user and support group liaison, was critical to the iterative development of the enablement device.

Critical design criteria adopted in development of the innovative 3 wheeled pyramid configuration include operation, efficiency, stability, safety, ease of attachment / detachment, versatility, wheelchair brand universality, manufacturability, aesthetics and cost.

Pyra-Aid™, a generation progressive device, has been manufactured and tested both in field and laboratory. Initial step / kerb mount tests for the three developed and manufactured prototypes have proven to be very promising.

Future work includes user centric and informed device optimisation, broader range of testing, alternative material and mass manufacturing processes investigation, castor alignment device development/testing and commercialisation / intellectual property advancement.

Market research indicates that a major and growing worldwide market opportunity exists for a momentum powered, universal, kerb mounting aid, which is inexpensive and has little maintenance commitments - Pyra-Aid™.

The author would like to pay special thanks to multidisciplinary third year group[7] colleagues, Siobhan, Laura, Sarah, Alan, Thomas and Stephen, who contributed most significantly to the research and progression of the product in early stage development and who were extremely supportive of and greatly encouraging to the author in advancing the device development, optimisation and validation as a highly challenging and rewarding final year project.

The contribution of wheelchair user support groups and industry has also been invaluable, as exemplified by the continuous support and encouragement proferred by the following to whom the author is greatly indebted:

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- **Mr. Donal Buckley, Managing Director, StyLite Designs**
- **Mr. Ger Flynn, Chief Biomedical Engineer , Cork University Hospital**
- **Mr. Ger Denieffe, Community Care Services**

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14. Pyra-Aid™ - "Life Without Obstacles"

Figure 68 Solid Model Design of Pyra-Aid™ J. Roberts

See Video of PyraAid™ Development / Testing on:

http://www.youtube.com/watch?v=9D_J80lWfcY