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Twin Winch Tail Hold Carriage: Design and Economic Analysis

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EXECUTIVE SUMMARY

The FFR Innovative Yarding System project aims to develop an alternative yarding system to increase harvesting productivity and reduce the cost of cable yarding. Earlier FFR work proposed a concept design for three innovative logging carriages controlled remotely from the yarder. A technical and economic feasibility appraisal of the initial concept compared with more typical current cable harvesting systems showed there was good potential to reduce harvesting costs.

The operational parameters and performance standards of the system were defined in the Alpha Prototype Development Plan. One of the logging carriages, a mobile tail hold carriage, is designed to shift the hauler skyline cable sideways across the cutover by remote control, reducing the number of time-consuming manual line shifts. A one-eighth scale alpha prototype tail hold carriage was built and demonstrated to the FFR Technical Steering Team in February 2015.

During the development stage it became evident that developing the whole new system including a low cost yarder was over ambitious given the time and resources available. The Development Plan for the Innovative Yarding System was revised to prioritise the completion of the beta prototype Twin Winch Tail Hold carriage (a full scale working version) to pre-commercial stage by 30 June 2016.

The design of the full sized version of the Twin Winch Tail Hold carriage has been completed and approval for construction of the carriage was gained from the Technical Steering Team in July 2015. This report summarises the design of the carriage and an economic assessment using the updated specifications from the completed design work. The objective of this assessment is to confirm the economic benefits indicated in the earlier feasibility analysis given the changes in the design.

This assessment showed that the twin winch tail hold carriage can improve productivity and will result in up to 12% savings in cost. The Twin Winch Tail Hold carriage design has been completed and the specifications have been updated. Construction is now underway.

INTRODUCTION

Objective

Cable harvesting with grapples is fast becoming the system of choice for cable harvesting contractors in New Zealand, catalysed by the increasing popularity of mechanised steep country felling and bunching and the desire to reduce the use of manual breakerouts to make operations safer. Grapples such as the Falcon Forestry Claw, the Alpine Grapple Carriage, the Acme grapple carriage and the Helihawk are all recent developments helping to achieve these objectives.

The aim of the FFR project Objective 2.3 Innovative Yarding System is to develop a new yarding system to increase harvesting productivity and reduce the cost of cable yarding. Developing new prototype products may also provide an opportunity to grow the harvesting machinery manufacturing industry in New Zealand.

Background

Earlier FFR work had indicated that if felled trees are bunched, grapple extraction is very productive. Preliminary simulation undertaken for the original PGP Harvesting Business Plan indicated the combination of felling, bunching and grapple yarding had the potential to deliver net cycle time benefits of about 30% [1]. One hindrance to achieving greater benefits is the downtime associated with cable skyline shifting. Where mobile tail hold machines are used, net cycle time benefits from bunching with grapple extraction are likely to be greater than 30%.

Arising from earlier work in the Innovative Yarding System project [2,3], a new idea to improve the way cable harvesting is undertaken in New Zealand was taken forward for further development. The idea of developing a system to improve the process of cable skyline shifting, especially where mobile tail holds could not be used, was proposed by Awdon Technologies Ltd (Awdon), a design and development company from Gisborne, New Zealand.

The original Awdon concept was an innovative system comprising a low cost yarder with a self-propelled grapple carriage working in unison with a lateral yarding carriage and a mobile tail hold carriage (instead of a ground-based mobile tail hold machine). All three carriages would be remote-controlled from the yarder cab. An alpha prototype development plan was developed in late 2013 [4] that specified the operational parameters and performance standards for the system. An international search of literature on the features of this system, such as grapple yarding, remote control, self-propelled carriages and automation did not reveal any existing patents or publications that were similar to the Awdon concept [5].

The most innovative element of the system was the Twin Winch Tail Hold carriage to which the cable yarder skyline is anchored. It contains two winch lines that are separately anchored to stumps or tail trees 60–70 metres apart at the back line of the cable setting. Letting one of the winch lines slacken while winching in the other line would allow the tail hold carriage and skyline to be moved sideways. A technical and economic feasibility appraisal of the initial concept system compared with current cable harvesting systems showed that the alternative extraction system had the potential to provide a 23% improvement in productivity over current tower hauler systems, and there was good potential to reduce harvesting costs [6].

The alpha prototype (one-eighth scale model) of the tail hold carriage was built and demonstrated to the Technical Steering Team in February 2015. On the basis of this alpha prototype the design for the beta prototype commenced. During the development, it soon became evident that the original concept of three yarding carriages was too ambitious for the time and resources available. Subsequently the development plan for the innovative Yarding System was revised to prioritise the development of the beta prototype Twin Winch Tail Hold carriage (full scale working version) only.

The revised Development Plan proposed completion of construction, field testing and development of the carriage to pre-commercial stage by 30 June 2016. An independent evaluation of the initial design of the beta prototype Twin Winch Tail Hold carriage was undertaken by a mechanical engineering consultant [7]. The engineering design of the full-sized version of the Twin Winch Tail Hold carriage has been completed (including some modifications arising from the independent engineering evaluation), and construction of the beta prototype carriage was approved by the Technical Steering Team in July 2015. This report details the design of the Twin Winch Tail Hold carriage (Project Milestones 5.5 and 5.11) and an update to the technical and economic analysis of the design given that the design specifications are now finalised (Project Milestone 5.9).

CONCEPT DESIGN FOR THE MOBILE TAIL HOLD CARRIAGE

The initial operational parameters and performance standards of the system were defined in the Alpha Prototype Development Plan. The mobile tail hold carriage (Figure 1) shall meet the following specifications:

1. One or two small winch drums capable of carrying 100 m of 26-mm to 28-mm rope
2. The winch drums to have pulling power of at least 4 tonnes
3. Have walk over guy capability
4. Carriage to weigh <1.2 tonnes
5. The winch drums to have rope spooling capability
6. The carriage to be remote controlled from the yarder
7. On-board camera system to monitor winch drums.

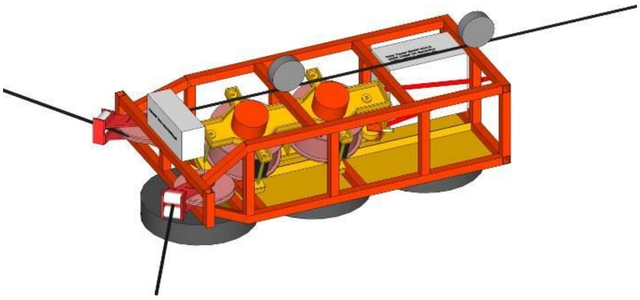


Figure 1: Alpha prototype mobile tail hold carriage with twin capstan winches

Figure 2: The Innovative Yarding System concept using the mobile tail hold carriage

The Twin Winch Tail Hold carriage design incorporates two winch drums and will weigh 2.6 tonnes, much more than the development plan target of 1.2 tonnes. The winch drums will be hydraulically interlocked, which has allowed a much smaller (30kW) engine to be incorporated into the design.

Figure 3: The Twin Winch Tail Hold Carriage

The carriage design will now meet the specifications set out below in Table 1, compared to the original specifications.

Table 1: Specifications for the Beta Prototype Twin Winch Tail Hold Carriage

Specification	Original	Achievable
Drum capacity (m)	100	65
Pulling force (tonnes)	4.0	7.0
Walk over guys	Yes	No
Weight (tonnes)	1.2	2.6
Rope spooling	If required	Not required
Camera system	Yes	Yes

A patent for the twin winch tail hold carriage has been attained (PCT Patent Application: PCT/NZ2015/050036) and the provisional patent for the innovative yarding system remains in place.

DESIGN OF CARRIAGE FRAME

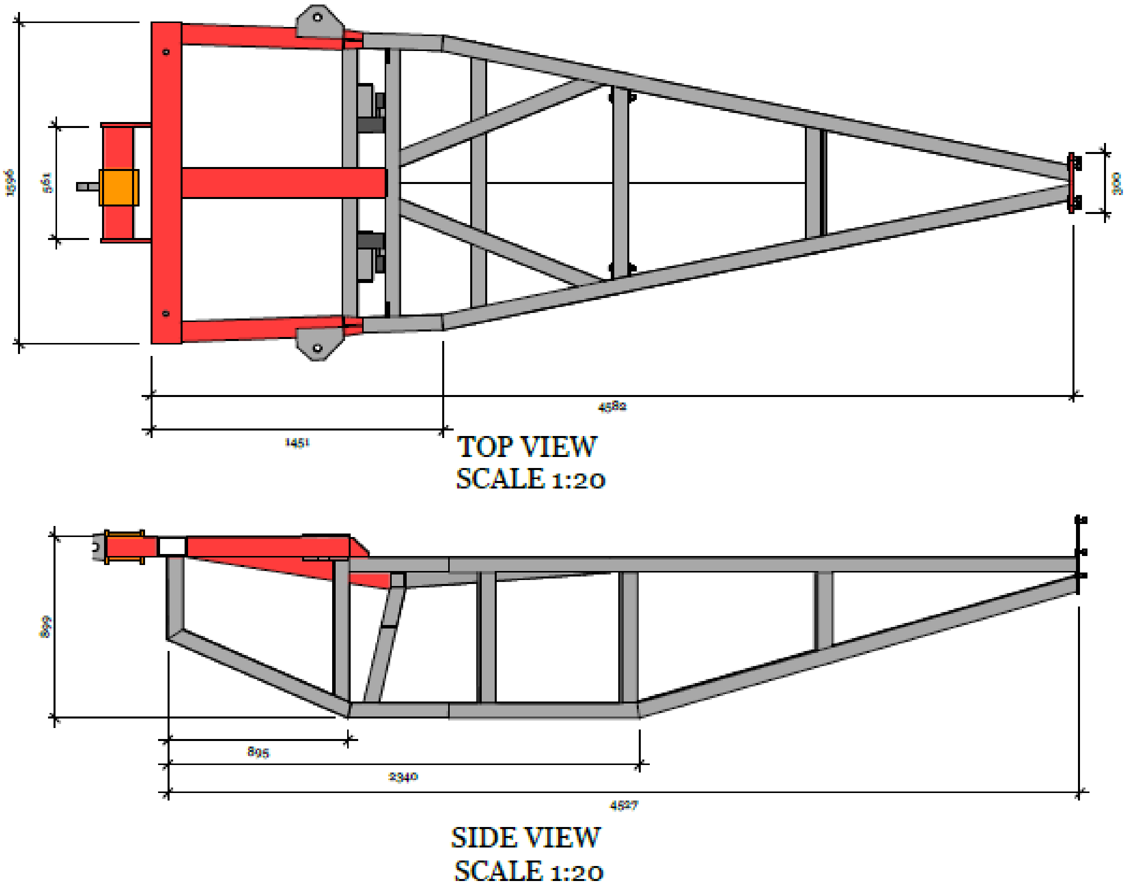


Figure 4: Carriage frame

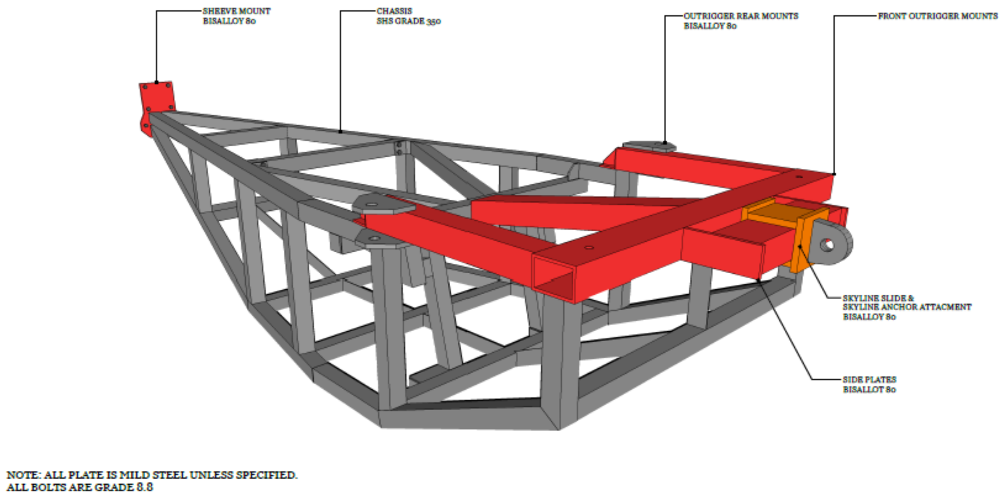
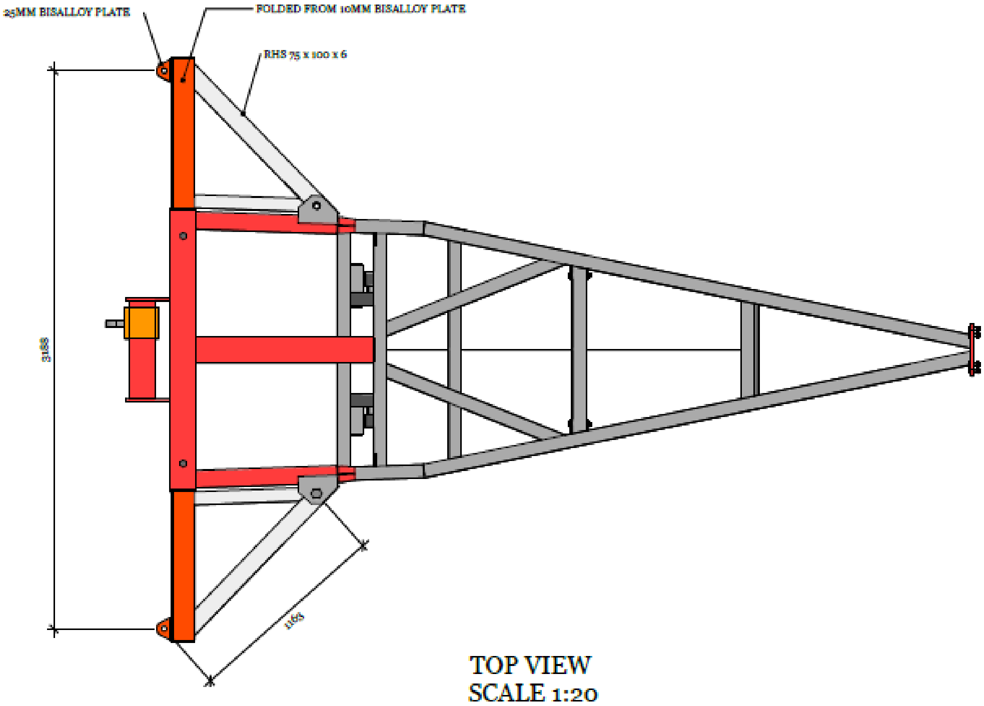
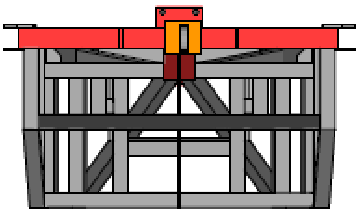


Figure 5: Mounts for outriggers and slide bar mechanism (orange) which will help balance carriage when winch ropes are unevenly spread

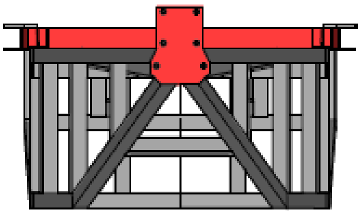


TOP VIEW
SCALE 1:20

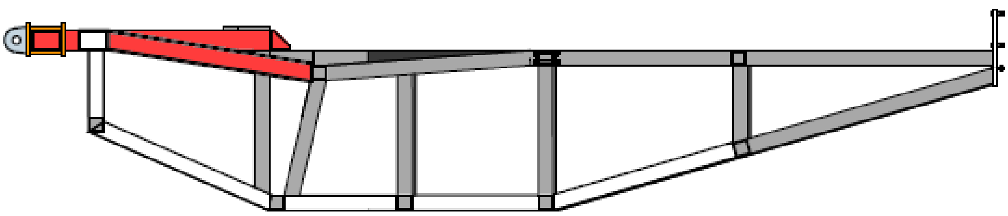
Figure 6: Front view of carriage showing moveable skyline fixing point (left) and rear view showing the fixing point for the sheave assembly



FRONT VIEW
SCALE 1:20



REAR VIEW
SCALE 1:20



SIDE SECTION VIEW
SCALE 1:20

Figure 7: Side view of frame assembly

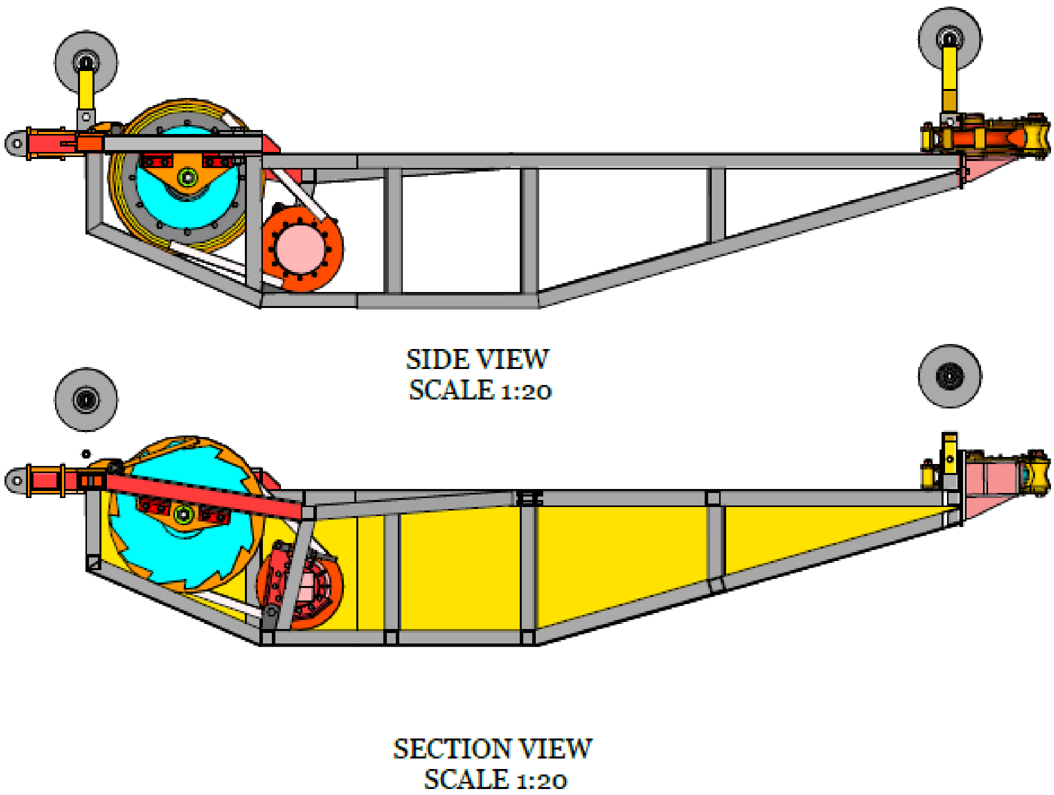


Figure 8: Layout of winches in carriage frame

DESIGN OF TWIN WINCH SYSTEM

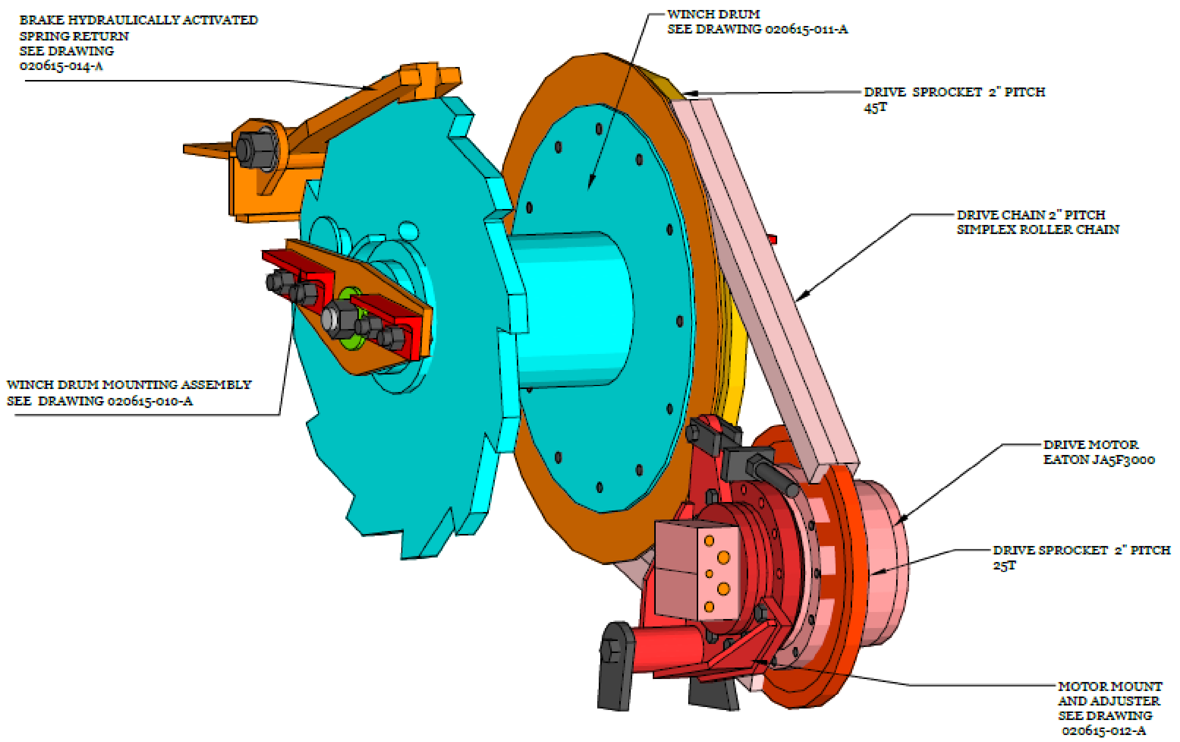


Figure 9: Winch drum drive assembly

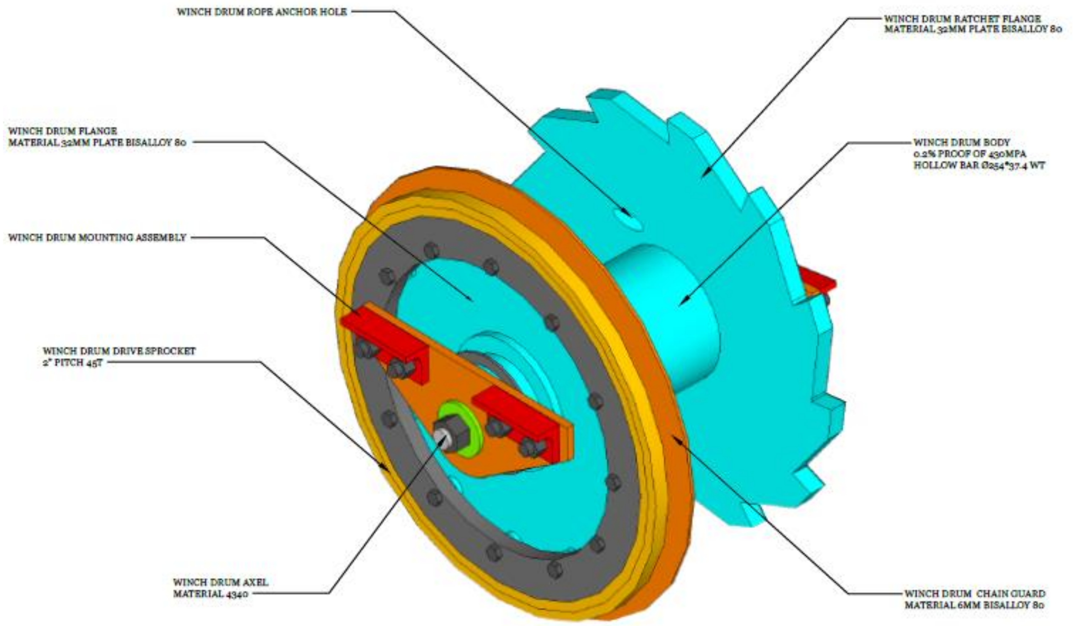


Figure 10: Winch drum assembly showing mounting brackets

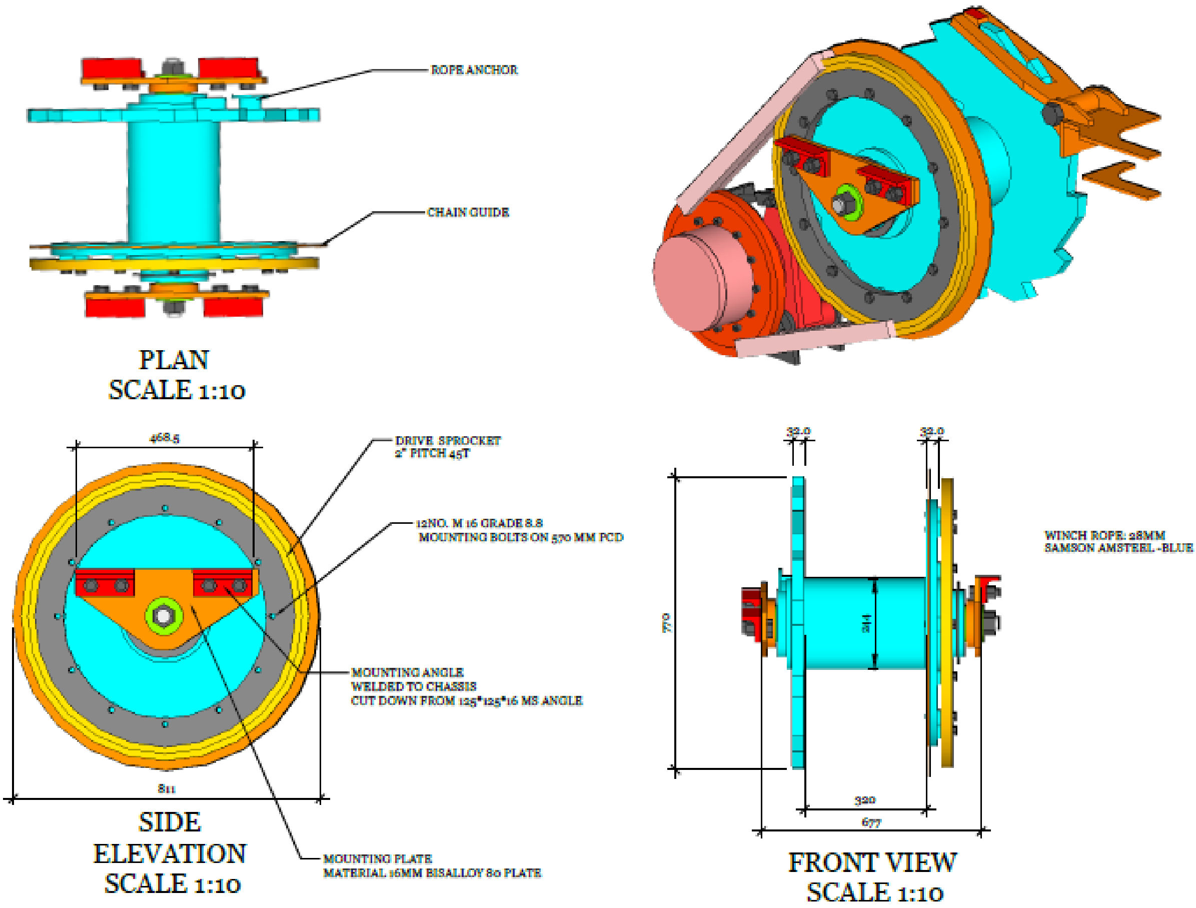


Figure 11: Winch drum assembly

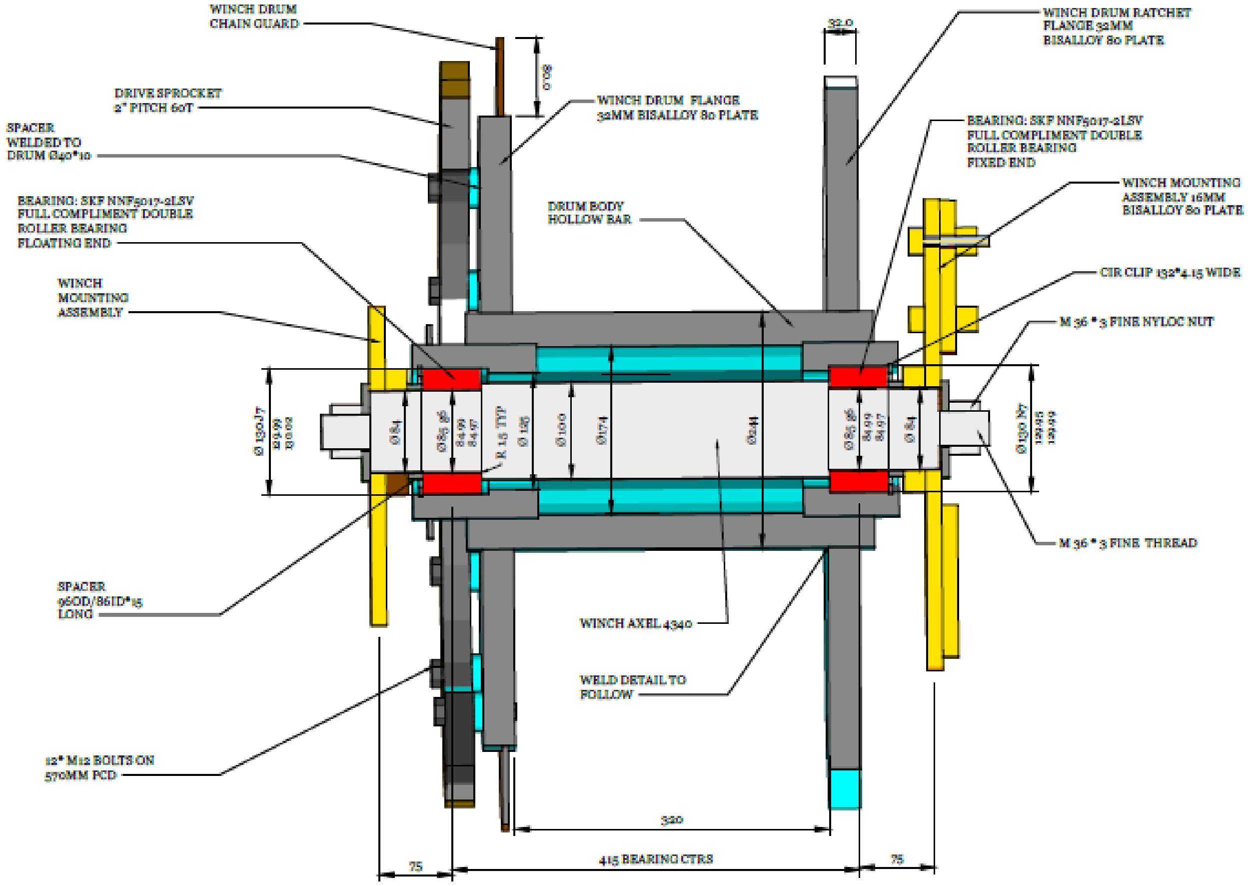


Figure 12: Winch drum shaft assembly

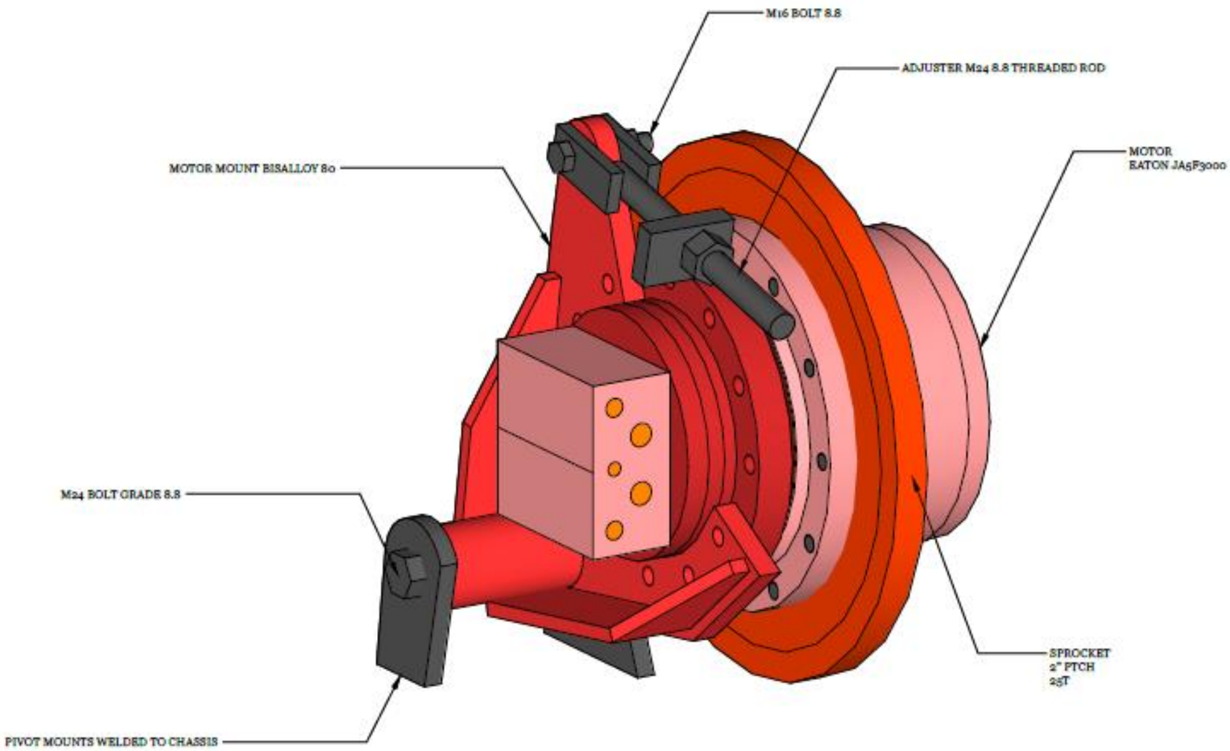


Figure 13: Winch drum drive motor

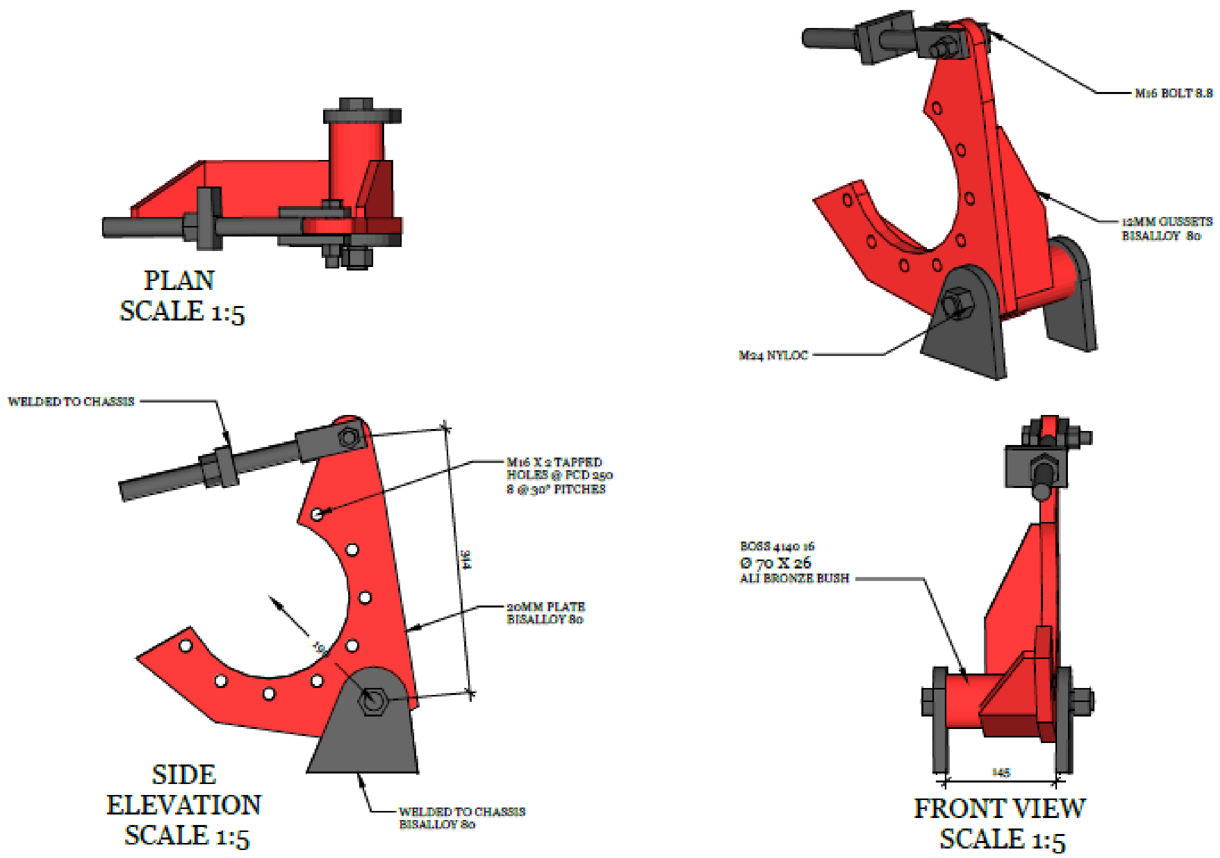


Figure 14: Winch drum drive chain adjuster assembly

DESIGN OF SHEAVE SYSTEM

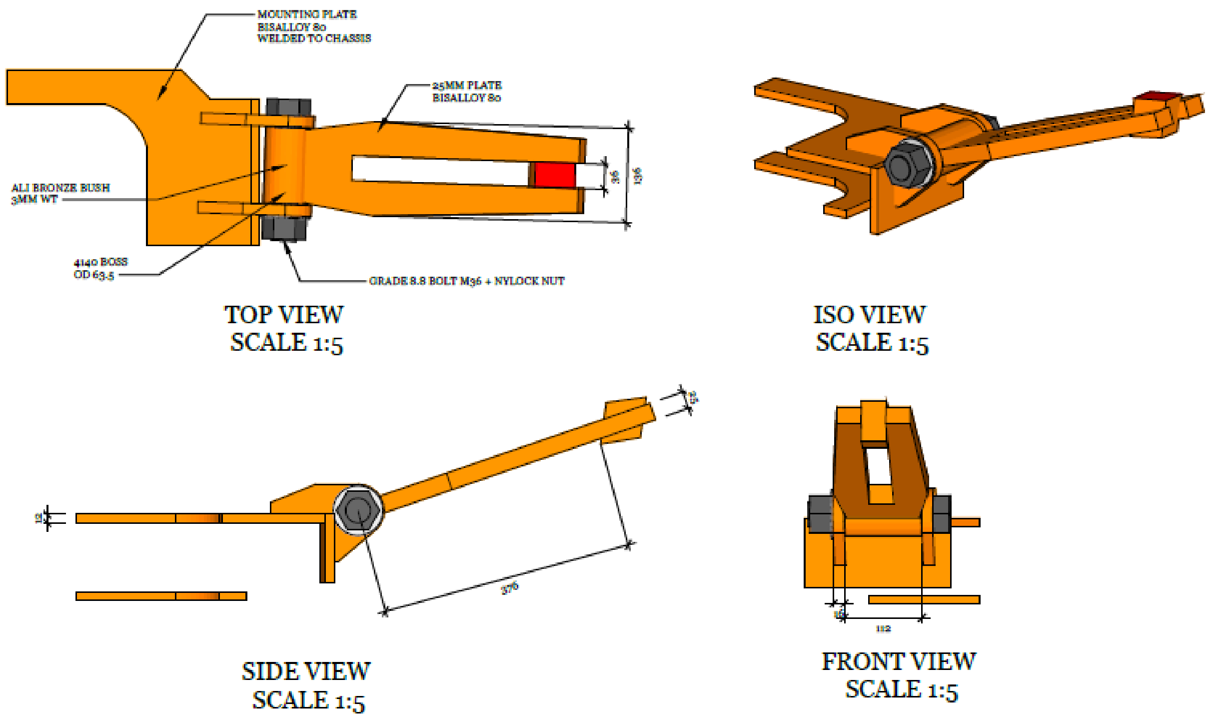


Figure 15: Mechanical Brake Assembly

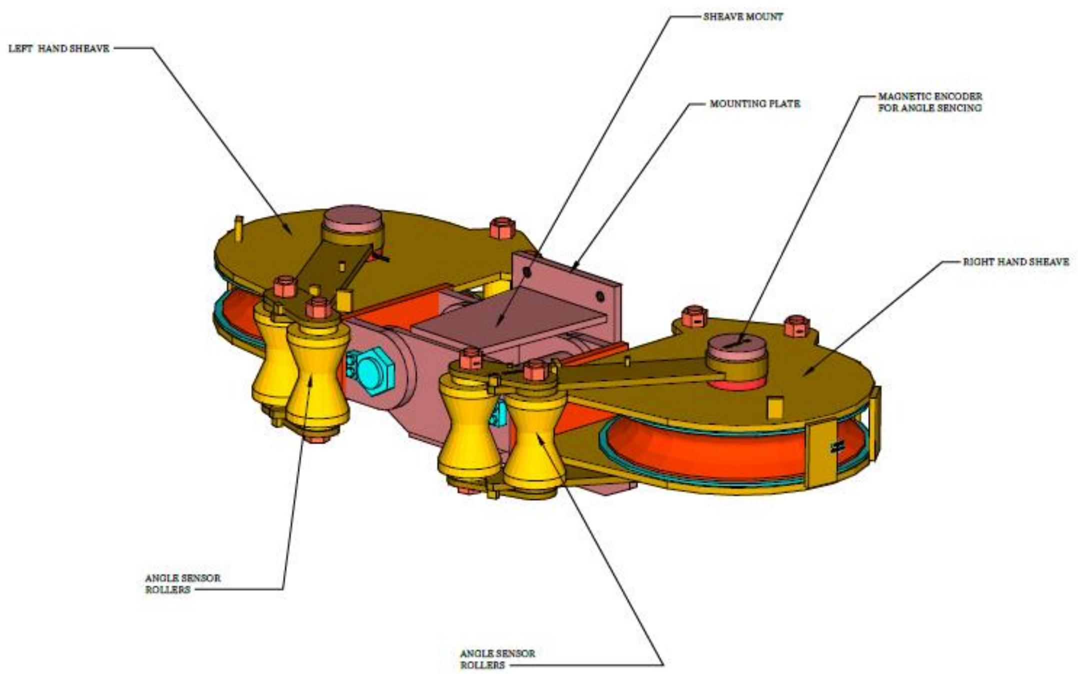


Figure 16: Sheave assembly

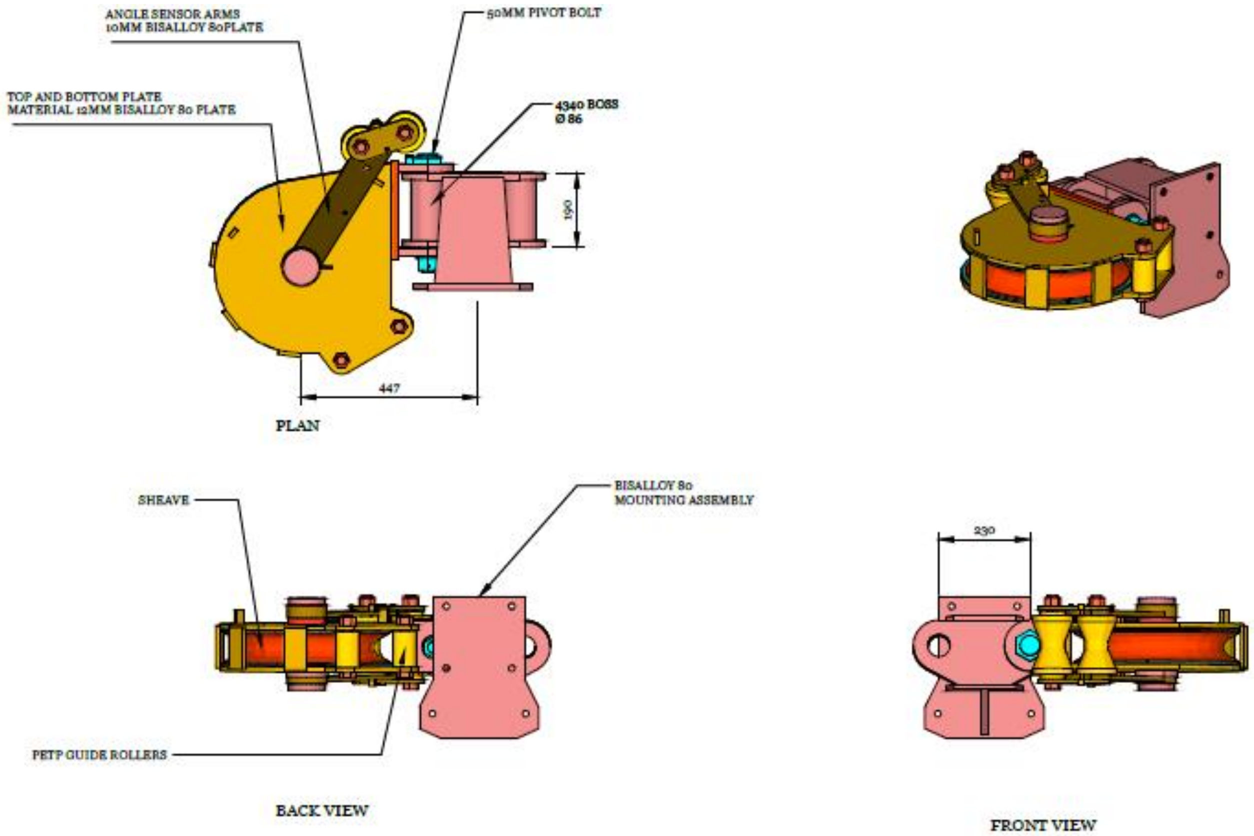


Figure 17: Sheave mounting assembly

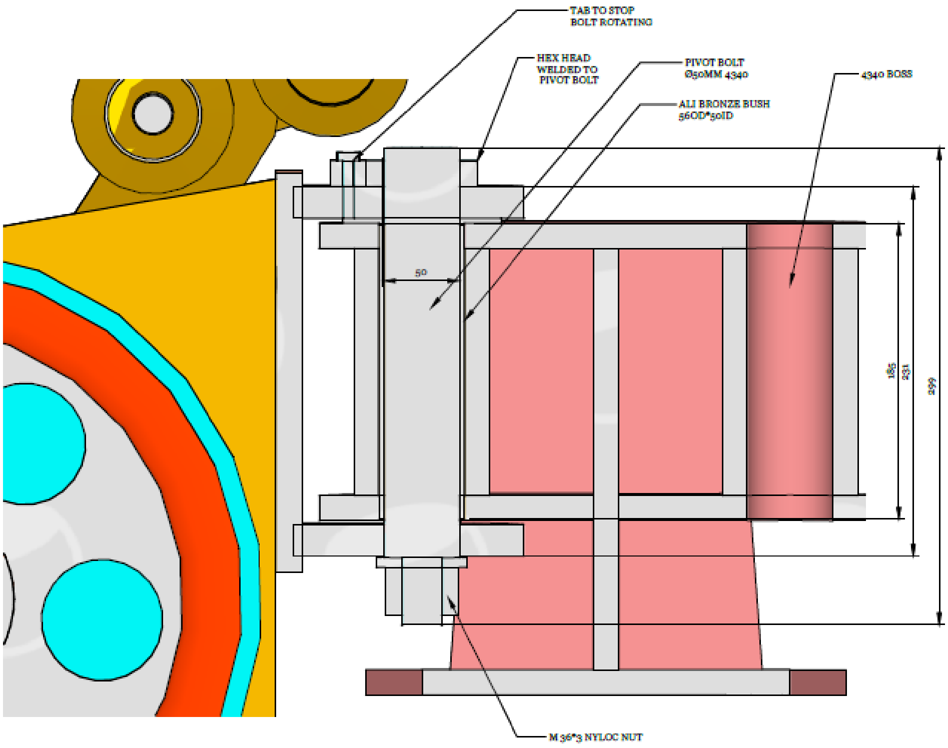


Figure 18: Detail of sheave mounting assembly

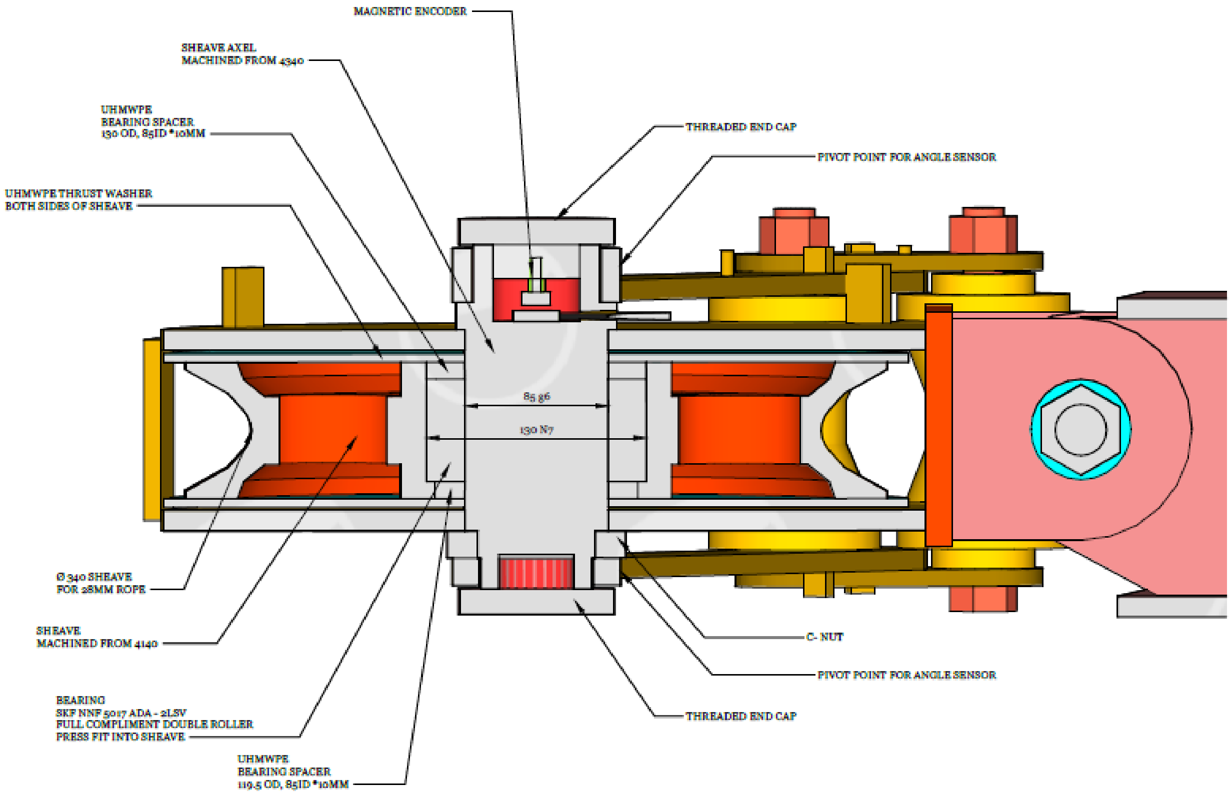


Figure 19: Detail of sheave assembly

DESIGN OF BLOCK SYSTEM

The overall layout of the blocks connecting the carriage to the skyline is shown in Figures 20 and 21. These are used during installation and removed when the carriage is in operation.

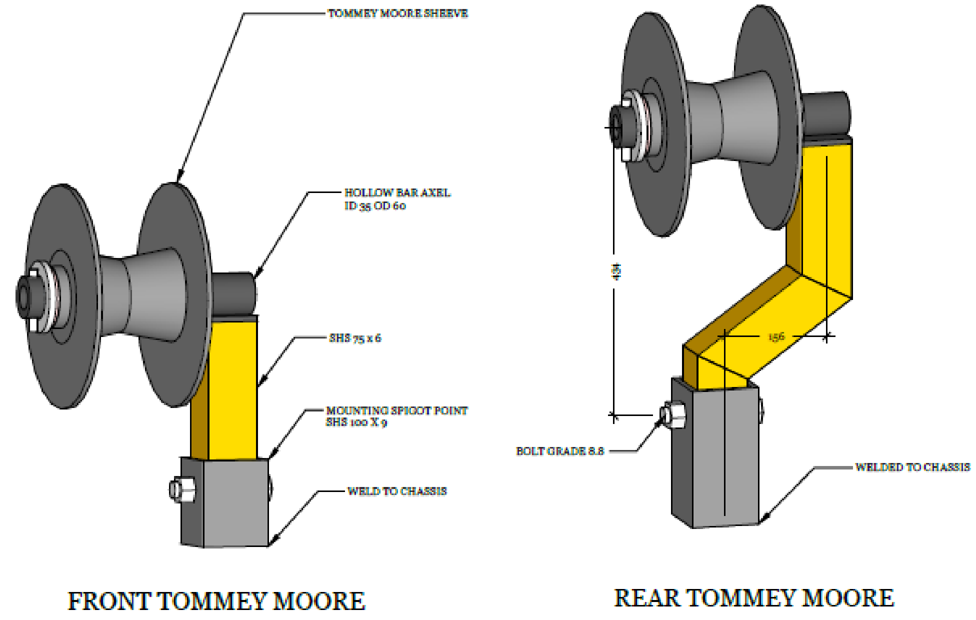


Figure 20: Tommy Moore sheave design

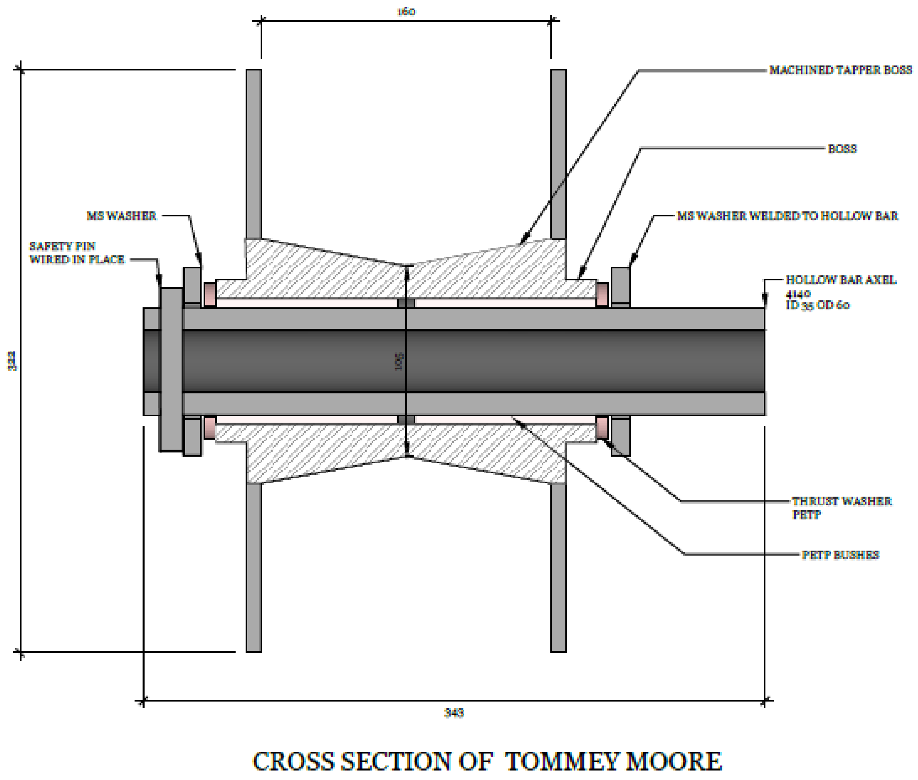


Figure 21: Tommy Moore sheave shaft assembly

ECONOMIC ANALYSIS

Payload Analysis

Additional analysis of tension, deflection and payload was undertaken by Dr Rien Visser of the University of Canterbury School of Forestry, to determine the effect of the tail hold carriage weight on potential skyline payload (Table 2).

Table 2: Tension, Deflection and Payload analysis (imperial measures with conversion to metric).

Skyline Calculations Rien Visser, Virginia Tech		**Calculate for*:**				
	Metric	**Tension**	Metric	**Deflection**	Metric	**Payload**
Skyline Tension (lbs)			21946	**48281**	21946	**48281**
Percent deflection (%)		**7.5**				**7.0**
Payload (lbs)	3636	**8000**		**0**		
Carriage weight (lbs)	2273	**5000**	2600	**5720**	2045	**4500**
Cable weight per foot (lbs/ft)		**1.65**		**1.65**		**1.65**
Cord length (ft)	518	**1700**	457	**1500**	518	**1700**
Carriage position (ft)*	229	**750**	442	**1450**	244	**800**
Cord slope (%)		**20**		**20**		**20**

21946	(kg)	Tension
48281	(lbs)	Tension
0.47	(%)	Deflection
7450	(lbs)	Payload
3386	(kgs)	Payload
250	Loss in Payload due to Tailhold Carriage	

$$Deflection\,(\%) = \frac{y_m}{l_d} \cdot 100$$

$$Tension = \frac{(C + P + \frac{1}{2} q \cdot l_d) \cdot (x(l_d - x))}{\% \cdot l_d^2 \cdot \cos\theta}$$

For the analysis it was assumed the tail hold carriage would weigh 2.60 tonnes and the grapple carriage would weigh 2.3 tonnes. The spreadsheet calculated the tension in the skyline at a stated deflection (21,946 kg at 7.5% deflection) and then calculated what proportion of the deflection in the skyline is reduced by the weight of the tail hold carriage (0.5%). The loss in deflection reduces the total available deflection in the skyline to calculate the allowable payload (3,386kg).

The analysis showed that at 7.5% deflection and 21,946 kg skyline tension, the skyline deflection was reduced by 0.5% to hold the twin winch tail hold carriage off the ground when sited near the backline. With a 2.60 tonne tail hold carriage and a 2.3 tonne grapple carriage on the skyline at 7.0% skyline deflection, the maximum payload that could be achieved while remaining within the safe working load of the 28-mm skyline was calculated to be 3.4 tonnes. The productivity and cost analysis then used a more conservative payload of 2.4 tonnes per cycle to estimate the potential harvesting cost of the operation with the twin winch tail hold carriage (Table 3).

Cost comparison

A desk-top feasibility analysis was undertaken. An operation with a twin winch tail hold carriage for efficient line shifting was compared to an operation that did not include the twin winch tail hold carriage and where ropes were shifted manually. The analysis investigated the likelihood of a cable logging operation reducing costs when using the twin winch tail hold carriage. The comparison is provided in Table 3.

Table 3: Cost comparison of current harvesting systems with the Twin Winch Tail Hold Carriage

Comparison of Harvesting Systems		
Elements	**Current Standard Tower Operation with Grapple Carriage - No Twin Winch Tail Hold Carriage**	**Current Standard Tower Operation with Grapple Carriage - with a Twin Winch Tail Hold Carriage**
Piece size (tonne)	**2**	**2**
Minutes per day available to work	**480**	**480**
Haul distance (m)	**280**	**280**
Out Haul (sec's)	30	30
Position Grapple (sec's)	20	10
In Haul (sec's)	80	80
Drop Load (sec's)	10	10
Un-hook (sec's)	30	30
Lift Ropes (sec's)	5	5
Cycle Time (minutes)	**2.92**	**2.75**
Contingincy 10% (minutes)	**0.29**	**0.28**
Time Per Cycle (minutes)	**3.21**	**3.03**
Move backline minutes per day	45	10
Reposition Hauler minutes per day	8	8
Rig up minutes per day	11	11
Rig down minutes per day	11	11
Mechanical Delay minutes per day	8	8
Operational Delay minutes per day	15	15
Cycles per day	**119**	**138**
Tonnes per cycle	**2.40**	**2.40**
Trees per cycle	1.2	1.2
Production per Day (tonnes)	**287**	**331**
Day Cost of Operation ($)	**9,702**	**10,006**
Unit Rate ($)	**33.86**	**30.21**
% Improvement	**12.10%**	

A standard tower operation operating with manual shifts was compared to the same operation with a twin winch tail hold carriage. Both operations were two-stage capable and included mechanical processing. For the purpose of the cost analysis, a conventional tower cost of $1.6 million and a grapple carriage cost of $80,000 were used. The results showed the twin winch tail hold carriage improves harvesting costs by 12%, reduced from the first analysis of 23% [6].

CONCLUSION

Incorporating a twin winch tail hold carriage into a cable harvesting operation will help to improve efficiency and lower harvesting system costs by around 12%.

The benefit of using a twin winch tail hold carriage with a more conventional skyline system using a grapple was not as favourable as a purpose-built system incorporating a low cost yarder and a self-propelled grapple carriage, preliminary analysis of which showed savings up to 23% [6].

The development process undertaken by Awdon has been rigorous and thorough. The process started with concept ideas and making small models (1/20th scale) of each idea, then an alpha prototype of the chosen idea was built (at one-eighth scale) and demonstrated. Engineering design and drawings of the beta prototype were completed and provided to an independent engineer who assessed the design [7] prior to commencement of construction. Full engineering drawings were then completed incorporating modifications arising from the independent evaluation. The next step is to build the beta prototype twin winch tail hold carriage, which is expected to be completed by 31 December 2015.

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