ATLAS project	**Transport of ATLAS SCT Endcap-A from NIKHEF to CERN**		
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Transport of ATLAS SCT Endcap-A from NIKHEF to CERN

This note presents the status of plans for transporting Endcap A from NIKHEF to CERN. It gives weights and dimensions of the transport box, and requirements for the safe transport. It also gives some insight into the choice of the correct size of wire-rope isolators.

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Distribution List:
Anybody

History of Changes

Rev. No.	*Date*	*Pages*	*Made by*	*Description of changes*
A	2/7/05	All	NP Hessey	Original document
B	7/8/05	Some	NP Hessey	Final corrections
C	8/3/06	Many	NP Hessey	SAAN proposal, Rutgers truck expected to be selected, no ballast

Contents

1 Requirements

The ATLAS SCT Endcap-A is a high-value (of the order of 10 MCHF material costs plus man-power) and delicate instrument for scientific research. It is an essential part of a much bigger project, and so must arrive intact and fully working. Apart from having been designed to be as light as possible while still suporting the required loads, it also has several thousand cable connections without strain reliefs, which must not be shaken loose during transport. It has to be moved from room H025 at NIKHEF, Amsterdam, The Netherlands – the room in which it is assembled – to the SR1 cleanroom at CERN, Geneva, Switzerland where it will undergo tests, final assembly, and integration into the TRT.

Dimension	Units	Value	Reference
Height	mm	2900	Drawing AFX70_4
Width	mm	2280	Ditto
Length	mm	4000	Ditto
Weight (total)	kg	1100	[1]
Weight (sprung)	kg	955	[1]

Table 1: Endcap-A dimensions for transport. Linear dimensions include space for movement of sprung load.

The Endcap will be transported in its assembly-frame and associated testbox (fig. 1), which will be mounted on a wheeled transport frame (fig. 2) to produce the complete object which has to be transported (fig. 3). Table 1 gives the main dimensions for transport.

The detector modules in the Endcap are built with very high precision. If they reach temperatures above 35 °C they can start to lose this precision. Therefore the temperature during transport must be guaranteed to be below 35 °C.

The detector modules can also be irreparably damaged by condensation. Therefore the atmosphere inside the testbox must be kept at below 80 % relative humidity throughout the transport, with 40 % preferred.

The carbon-fibre Endcap support structure has been kept as light as possible. In particular, it is designed only to hold its load in the vertical direction. Therefore the structure must not be significantly tilted during the transport; the tilt angle should not exceed 10 °during handling or transport.

The centre of gravity of the box is not at its geometric centre. One end of the box has all the services and more support structure, making it heavier. This end is recognisable by the presence of a large ring of electronics circuit boards and the cooling pipe connections. Figure 3 shows the position of the centre-of-gravity: it is centred in the width dimension, but in the length direction it is about 300 mm from the geometric centre towards the services end; and it is 1415 mm above ground-level when sitting on the transport frame wheels.

The disc-insertion beam will be removed before transport.

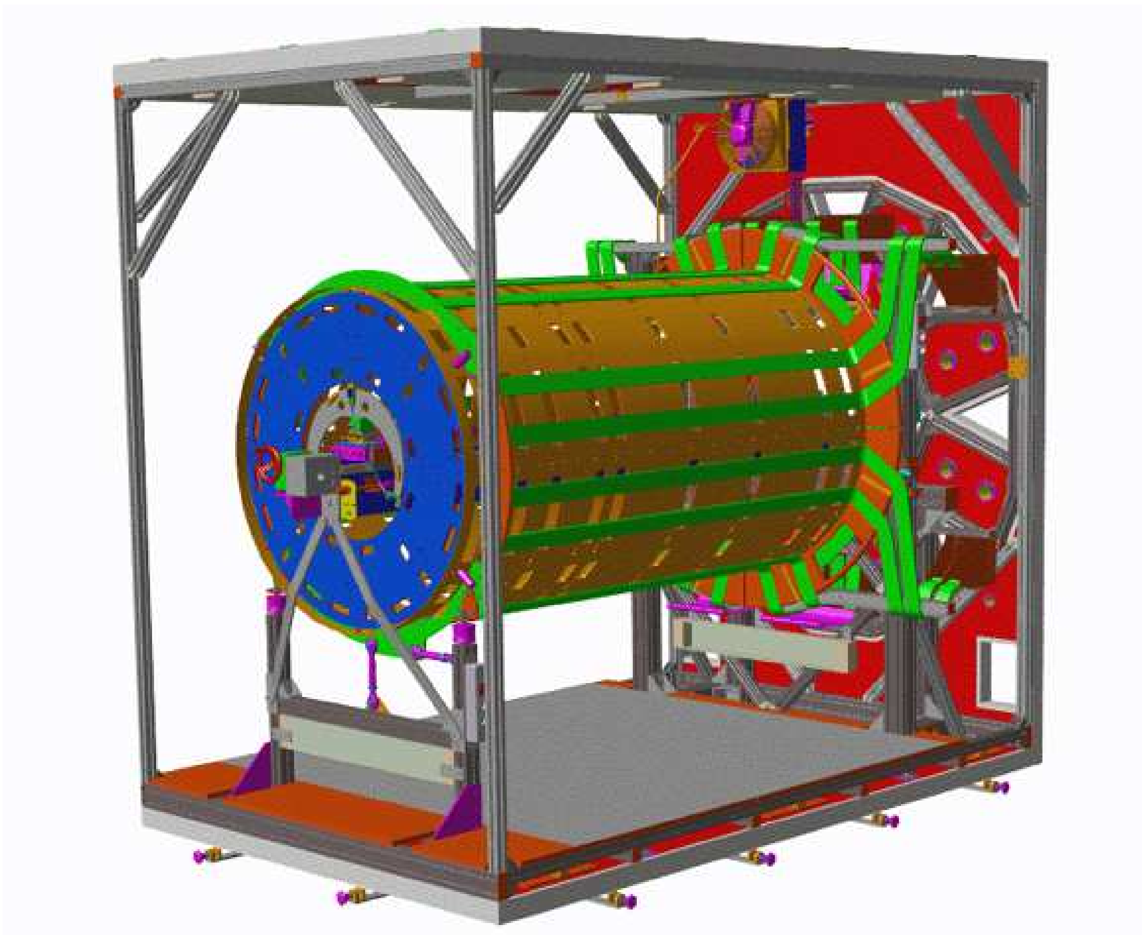

Figure 1: The assembly tooling and test frame, with the Endcap completed; the side panels which will be present during transport have been removed.

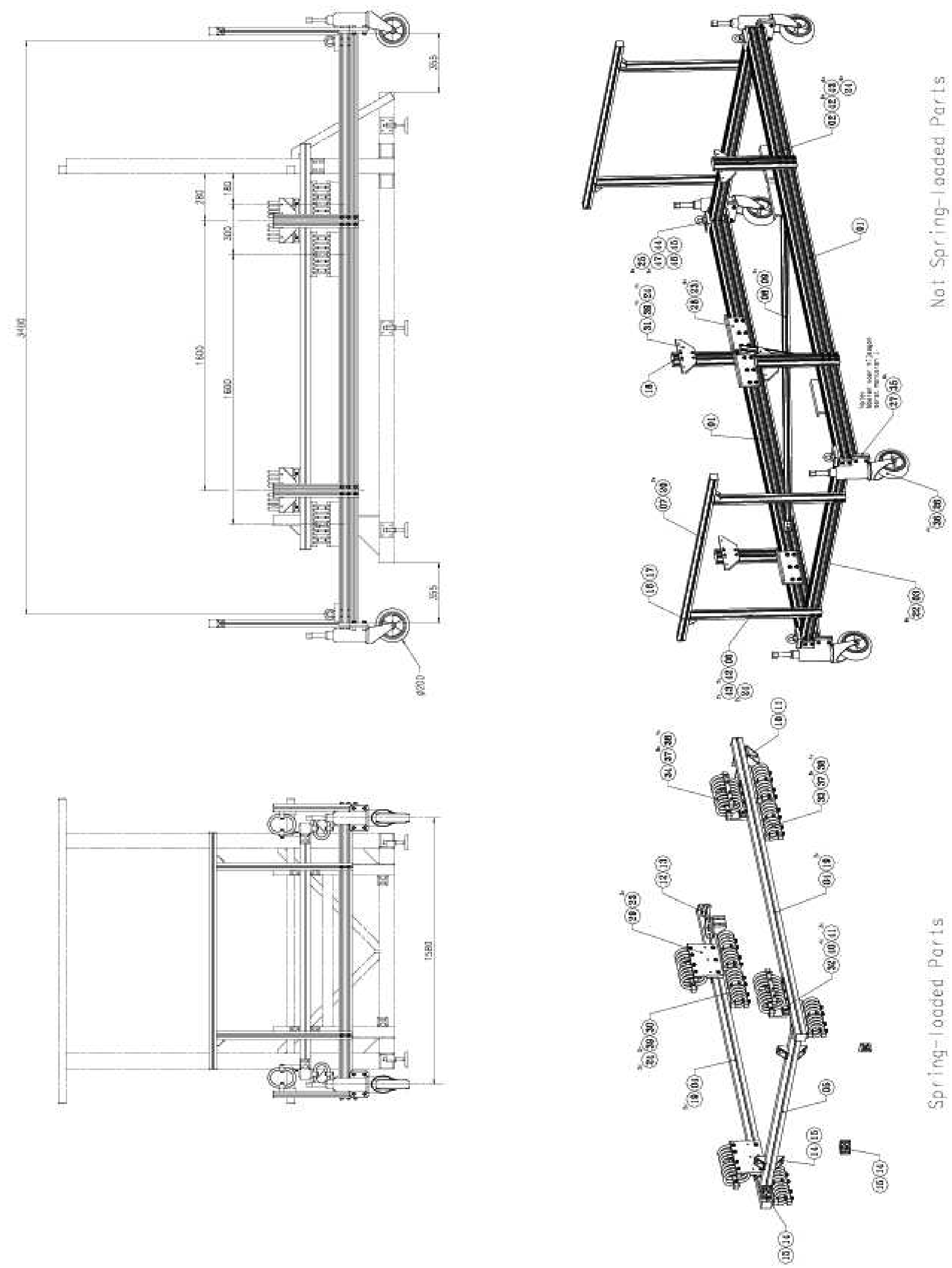

Figure 2: Transport frame which will be added to the assembly frame for the transport (drawing AFX71).

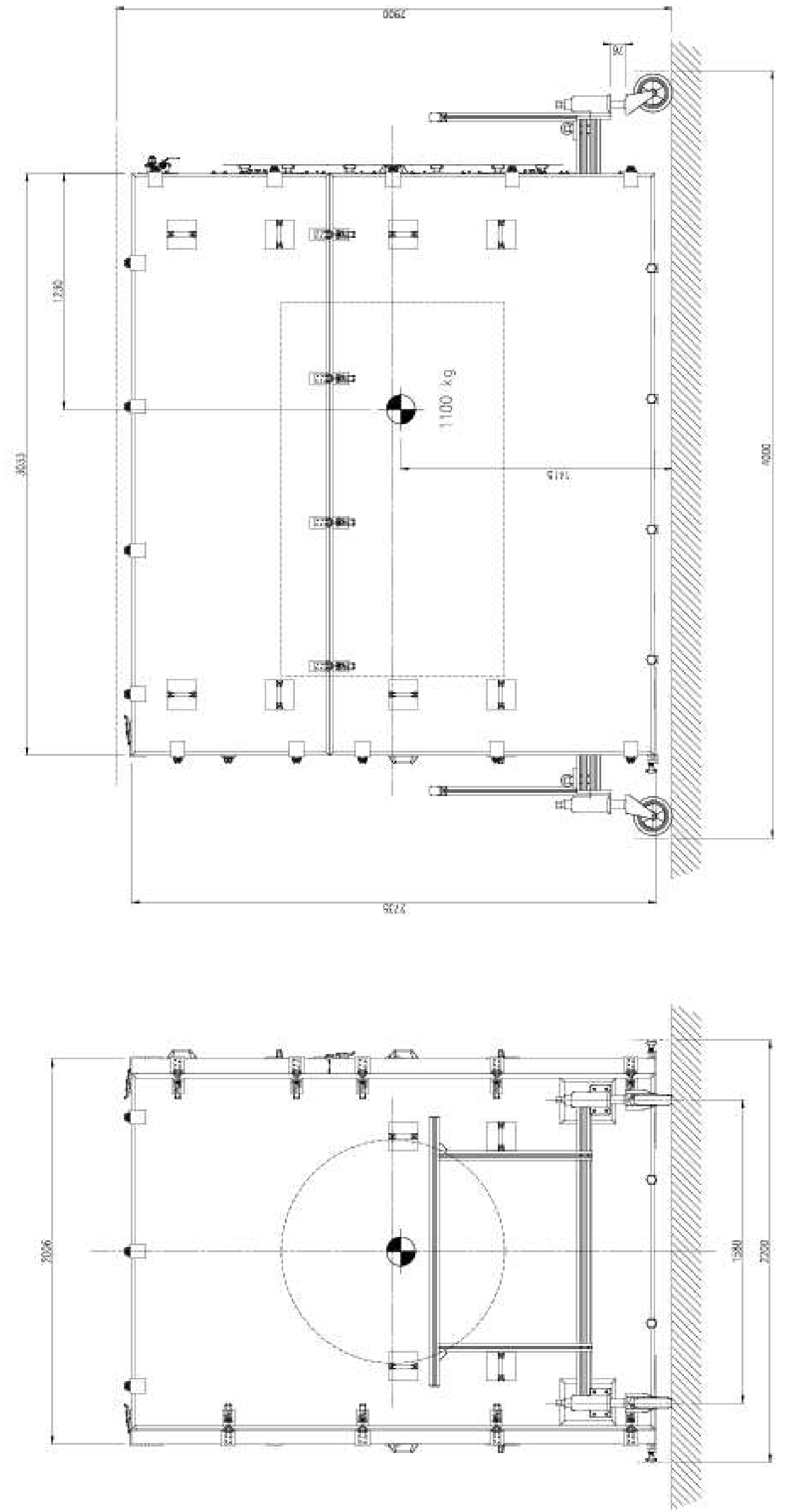

Figure 3: The package to be transported, from which the figures in table 1 are taken, with 80 mm added to the width for spring movement (drawing AFX70_4).

2 Transport Frame and Handling

The transport frame is based on two long beams supported at their ends on wheels. The beams are connected to each other by a framework of smaller beams. To keep the height of the structure low enough for a standard trailer, the frame has to go inside the panels rather than below it. This makes it unsuitable for using a fork-lift truck to load the Endcap onto a lorry. If a fork-lift is to be used, a large palette needs to be built for the wheels to sit on; on no account should the base panel be used for lifting.

Also the beams are very long, giving a relatively low resonance frequency. This frequency has been raised by changing the beams to the largest Bosch profiles possible, and also by the addition of diagonal cross members. Note that the positioning of these members is crucial for their correct funtioning: one end needs to be as near the wheels as possible, the other end as near to the middle of the other beam as possible. In this geometry, the cross beam helps reduce sag at the middle of the long beam, stiffening the frame and so raising the resonant frequency.

The whole assembly can be moved around on a flat surface easily by two people pushing on the transport frame. However, minor bumps are better overcome with a cable winch. The ground clearance is very small – 50 mm – and the wheel base very long. This prevents the use of short ramps, and even makes movement over the uneven surface of the NIKHEF car park difficult. For ramps to be used to load the Endcap into a truck, they would have to be about 20 m long to comfortably avoid the testbox bottoming out at the entrance to the truck. Alternatively, extensions could be added to the wheel mounts to increase the ground clearance if necessary.

The transport frame is attached to the assembly frame by wire-rope isolators. These give 3D shock-absorbtion and damping.

The long beams are equipped at each end by eye-bolts suitable for lifting the entire load. These have been tested with 50 % overload at NIKHEF. The recommended lifting method is via an H-shapped spreader frame, with the 4 tips of the H above the four eyes, and connected by equal-length vertical slings. These 4 tips are also connected to the crane hook by 4 slings in a pyramid shape, see fig. 4.

If no H-beam is available, then a long-beam can be used. Two slings from the hook should go diagonally outwards to near the top-side of the ends of the long-beam. At each end below the beam, two slings should go out diagonnaly to the eye bolts, see fig. 5.

3 Choice of isolators

The isolators have two main functions: to reduce accelerations during handling, including shocks from minor drops etc.; and to minimise vibrations during the long journey to CERN.

3.1 Behaviour of Wire rope isolators

A spring will reduce accelerations due to a sudden, short-duration shock such as being dropped. However, a continuous vibration near the resonant freqency of the spring and load system will be amplified, with a factor depending on the damping of the spring – the more the damping, the less the amplification of the vibration. The wire-rope isolators chosen have a high damping coefficient, equal to 15 % of the critical damping. The behaviour for different frequencies of such a system is described in terms of the transmissibility

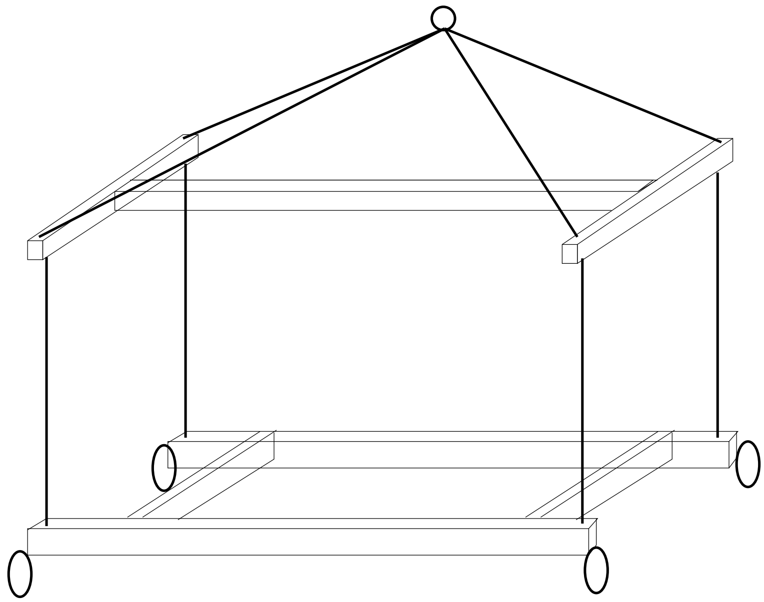

Figure 4: Lifting principle with an H-beam.

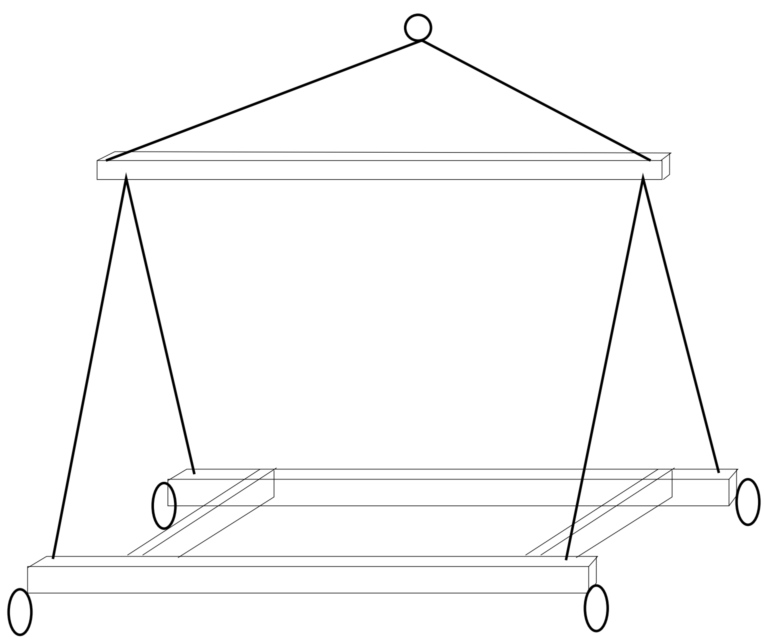

Figure 5: Lifting principle with a long-beam.

$$TR = \sqrt{\frac{1+(2\xi\beta)^2}{(1-\beta^2)^2+(2\xi\beta)^2}} \tag{1}$$

where β is the frequency in units of the resonance frequency, and ξ is the damping as a fraction of critical damping. Figure 6 shows the transmissibility of a spring with 15 % damping. It peaks just below the resonant frequency, at $\beta = \sqrt{1-\xi^2}$.

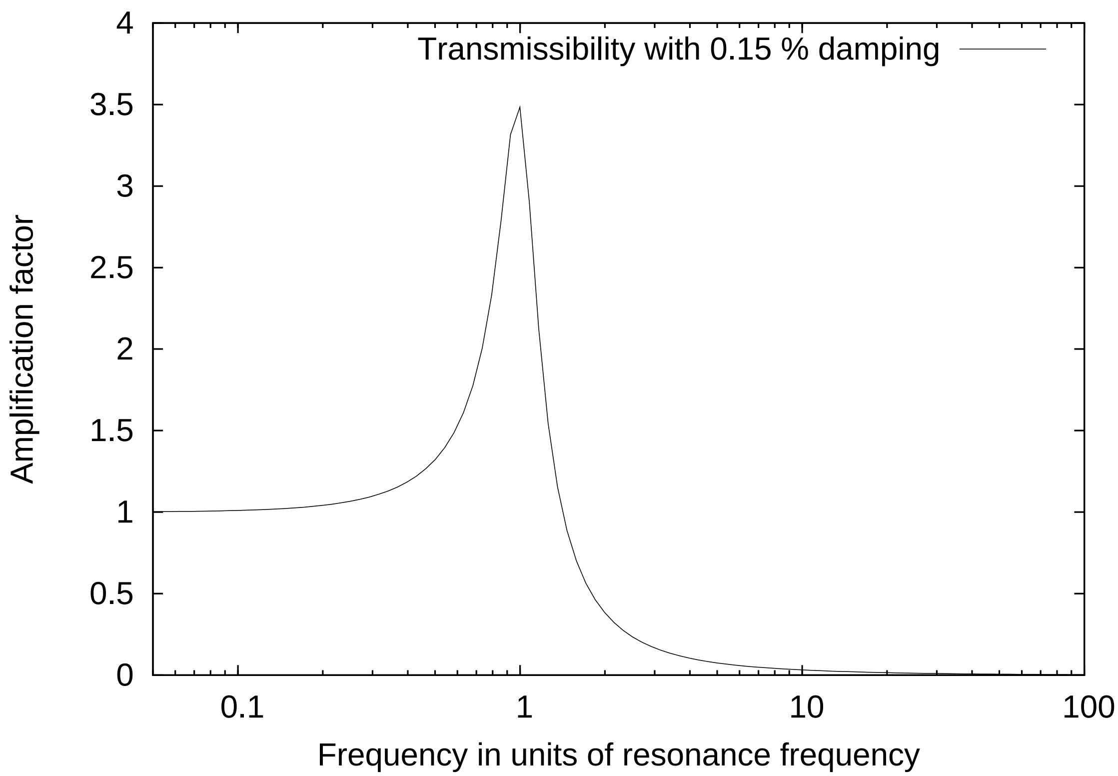

Figure 6: Transmissivity of springs with 15 % of critical damping.

The resonance frequency is given by

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{c}{m}} \tag{2}$$

where c is the spring constant and m is the mass of the load on the spring. These equations apply to Hooke's law springs; the wire rope isolators are far from Hooke's Law springs, but the equations can be reasonably applied to small vibrations around the equilibrium point of the isolator, using the value of c appropriate for the deflection of the isolator. There are three important motions of the springs: compression, shear, and roll. Shear and roll have the same load/deflection curves. For small loads, compression is very much stiffer (factor 10 to 100). But compression stiffness decreases with load, while shear and roll stiffness increase with load, so that at high loads the stiffnesses in the three directions are similar. The isolator load F_i for the spring-type i vs. deflection u curve in one direction is well approximated by

$$F_i = k_i u^{\gamma_i} \tag{3}$$

where k_i and γ_i are constants for spring-type i. Within a family of isolators, for one direction, the γ_i are all equal, while the k_i decrease as the springs get heavier. The spring constant can then be replaced by

$$c(u) = dF/du \tag{4}$$

The energy stored in a spring when the deflection increases can be calculated by integrating the load curve between the start and end deflections

$$E = \int_{u_1}^{u_2} F du \tag{5}$$

which can be used for example to calculate the maximum deflection u_2 when the load is dropped from some height h giving an absorbed energy *mgh*.

The vibration spectrum during transport depends on many factors and is difficult to predict. However, the important range can be estimated from wheel speed and diameter. An unbalanced wheel will give a vibration with fundamental frequency equal to its rotation frequency, $f = v/(2\pi r)$ for a truck velocity v and wheel radius r. Typical steady velocities occur in the range 50 to 100 km/h, and wheels are usually 0.75 m diameter, but can be up to 1 m. These figures give a range of frequencies from 4 to 12 Hz. As figure 6 shows, above a frequency $f \approx 1.4 f_0$, the transmissibility is less than 1 and vibrations are damped. Below this frequency, vibrations are amplified, by a factor up to 3.5.

Enidine make several series of wire rope isolators WR2, WR3, ...WR28. As the series number increases, the wire rope diameter increases giving higher stiffness, along with bigger dimensions and weight of the unit. Within a series, there are several units which get *less stiff* with increasing dimensions: they have the same rope, so a larger coil radius gives a softer spring. However the energy absorbtion ability always increases with increasing dimensions.

A set of isolators and a design for positioning them between the assembly frame and transport frame has been made [1]. It uses 6 WR20-600-08 with their stiff direction vertical, and 4 WR20-800-08 with their stiff direction horizontal in the side-to-side (width) direction. The properties of this design have been calculated and are presented in the report. This configuration has been tested in a trailer driven around Amsterdam, with the results also presented in that report.

The main predictions are that a 100 mm vertical drop will lead to a maximum vertical acceleration of 6.2g; an emergency stop at 1g (to be road-worthy in Europe a vehical must be able to brake at above 0.8g) will lead to a horizontal front-back acceleration of upto 2.5g, depending on how fast the brakes are applied; and steady vibrations will be amplified most at 9.8 Hz by a factor 3.5.

The main results from the transport test are (i) The maximum recorded acceleration on the shock loggers was 1.5g and (ii) the maximum for emergency stops was about 2.4g: the loggers did not read out very often during the emergency stops (possibly they ran out of batteries before then); however the maximum deceleration seems to have been about 1.4g deduced from the displacement sensors plus the truck deceleration of 1g.

3.2 Choice of spring type

Table 2 gives the results of calculations of resonance frequency and maximum acceleration and displacement, for different WR20 series springs. The aim is to give a feel for how things vary.

Only vertical (compression) movement of the 6 springs with their compression-direction vertical are taken into account. The 4 horizontal springs have very little effect. The k_i and γ_i were estimated by reading off the log-log graph in [1]. The resonant frequency is for a pure vertical mode; in fact, the full modelling in [1] shows all the six modes of vibration mix, giving lower and higher frequencies of more complicated motions. The mass assumed is 955 kg. Resonant frequency goes as $m^{-0.5}$, while the maximum acceleration following a shock goes as $m^{0.5}$ in this simple model.

The equilibrium displacement is the compression just due to the static loading. The drop displacement shows how much the springs will move – if they don't bottom out first – following drops from different heights.

Type	k_i	γ_i	Eq. defl. [mm]	Res. f [Hz]	Max accel/disp from drop height [mm] 10		100		200	
					g	[mm]	g	[mm]	g	[mm]
WR20-200	2188	0.651	0.6	16.5	3.7	4	9.2	18	12.1	27
WR20-300	1742	0.662	0.8	13.9	3.3	5	8.2	20	10.8	31
WR20-400	1505	0.636	1.1	12.2	2.9	6	7.1	23	9.3	35
WR20-600	1094	0.651	1.7	9.7	2.4	7	6.0	27	7.9	42
WR20-700	823	0.648	2.7	7.8	2.0	8	5.1	33	6.6	50
WR20-800	721	0.642	3.3	6.9	1.9	9	4.6	36	6.0	55
WR20-900	590	0.642	4.6	5.9	1.7	10	4.1	40	5.3	62

Table 2: Estimates of resonance frequency and shock acceleration/displacement in a simple model using equations (3) to (5), for different isolators.

The trade off is clear: if you want a lower maximum acceleration following a shock, the bigger springs should be chosen. But then the resonant frequency decreases, so connectors etc. will get more vibration during the journey. The choice of WR20-600 has a resonant frequency at the top end of what can be expected, and a reasonable cushioning effect against shocks. Note also that a drop above 200 mm (not very high!) could cause springs to bottom out, giving much higher accelerations.

The Barrel SCT transport was made with 8 isolators of type WR20-700, typical load 700 kg, giving a resonance frequency of 8 Hz, 10.4*g* acceleration following a 100 mm drop, with deflection 38 mm [2]. The proposal of 6 isolators of type WR20-600 for the Endcap has resonance frequency 10 Hz, 6*g* following a drop from 100 mm, and 27 mm travel.

4 Choice of trailer type

For minimum vibration and shocks we require an airbed suspension trailer. We prefer an air-conditioned, dehumidified one. Rutgers can supply van de Wal with a suitable tractor trailer unit. The tractor is also air-sprung. This means no ballast is necessary. It does not have a removable roof, so is more difficult to load. The Rutgers trailer has a side entry door, allowing easy access for securing the front of the Endcap. The trailer dimensions are 3.000 m door height, 13.410 m long, 2500 m internal width; se figure 7. No power is available in the trailer.

Sturdy attachment points are needed so that the Endcap will not shift in a minor collision of the truck. SAAN will make an offer for producing these.

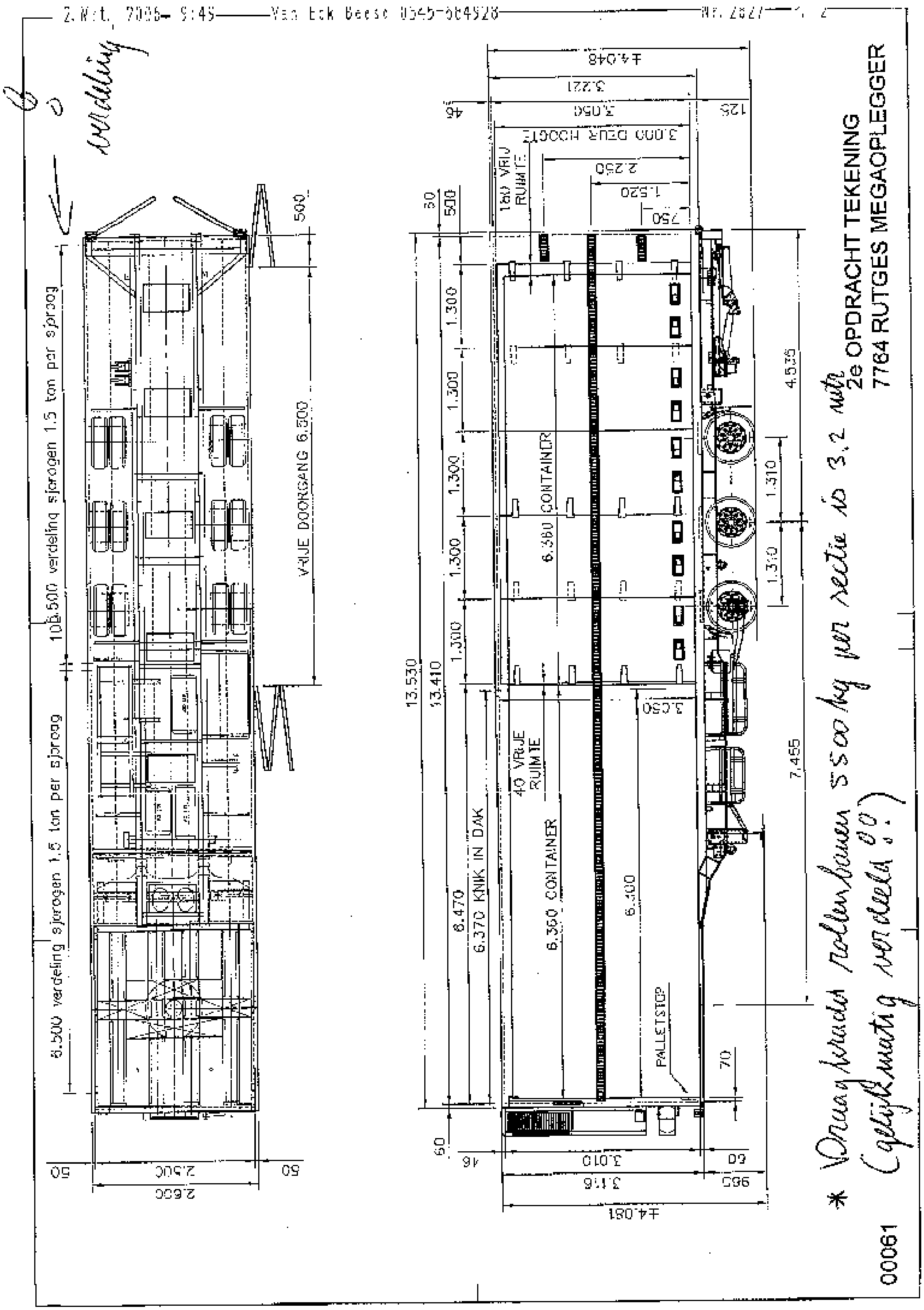

Figure 7: The trailer proposed by van de Wal/Rutgers

5 Choice of loading and unloading methods

5.1 NIKHEF Site

After completion of all NIKHEF assembly work and testing, the Endcap and assembly frame will be prepared for transport by addition of the transport frame, the extra rubber shock absorber at the services-end stub wing, removal of the disc-insertion beam, securing all components, completion of all ESD safety actions, addition of silica-gel bags, removal of the Bosch lights, and all other tasks needed for maximum safety during the transport.

The Endcap is assembled in room H025 at NIKHEF. This has a large removable window down to ground level through which the Endcap will be wheeled. The ground outside slopes away, and so a wooden platform has been constructed (figure 8)to give a level surface at the same height as the H025 floor. The platform extends almost to the road. We propose to extend it all the way to the road. Some bollards have to be temporarily removed for access to the road. After wheeling the Endcap onto the wooden platform, we will cover it with an anti-static wrap to keep it clean.

Figure 8: The wooden platform used to roll the Endcap out of the assembly clean room.

The platform sits underneath office buildings. The clear height from road level is 4.25 m. This makes crane access to the platform difficult; when the Endcap is on the platform, there is only about 1 m clearance above it.

Since the roof of the trailer cannot be removed, the Endcap will have to be wheeled in. For that, SAAN propose constructing a large palette suitable for fork-lifting. This would be placed on blocks on the road, so that it is level with the wooden platform. The Endcap is wheeled onto the palette. Then a fork-lift truck moves the pallette to the trailer, and lifts it to the height of the trailer. The trailer and pallette are secured on jacks to prevent movement when the Endcap load transfers from one to the other. The Endcap is wheeled into the truck and secured.

Plates or U-profiles may have to be placed over the rollers in the trailer, to give the transport frame wheels a smooth surface to roll on.

5.2 CERN Site

The SR1 building has a crane (max. height to be confirmed) and large access door (4 m high, to be confirmed).

If an open trailer from CERN can be found at about the same height as the transport trailer, then the Endcap can be wheeled from one to the other via ramps. The Rutgers trailer can adjust its height to match the open trailer. The open trailer can then be driven into the SR1 loading bay, and the SR1 crane used to off-load the Endcap onto the SR1 floor. We need to check the height of the SR1 crane to see if this is feasible.

Alternatively, the pallette used to load at NIKHEF could be used. The pallette would be secured on blocks by the truck; the Endcap is wheeled out onto it; a fork-lift then lowers the pallette to the ground in the SR1 crane area. The crane offloads from the pallette to the floor.

6 Monitoring during the transport

In case anything goes wrong, it will be useful to have shock, temperature and humidity loggers in the truck and in the Endcap enclosure. However these will not prevent a problem. A video camera could be set up in the back of the truck to film the movement of the box during the first 30 minutes or so of the transport.

If by mis-design or mechanical problems of the truck there are significant vibrations or shocks to the structure, the sooner we find out about it the better. We propose to check the logger data and video after 30 minutes or so. If a serious problem is found, remedial action has to be taken or the transport postponed.

7 Summary

The main requirements to ensure a safe transport of Endcap-A have been given.

There are a few outstanding issues for loading and unloading, particularly the latter. these need to be finalised urgently. Contracts for insurance, loading and transport need to be placed. We hope CERN can carry out the offloading; this needs to be discussed urgently.

References

[1] SCT Endcap-A Cylinder Transport, Corijn Snippe (NIKHEF), 24 June 2005.

[2] Reference lost.