A Self-Leveling and Swiveling Forestry Machine Cab

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ABSTRACT

A radical, new innovation with regards to forestry machines is the design of a cab suspended from an arched column connected to a swiveling socket. The purpose of the design is to reduce the amount of skewed and twisted work postures, which are often frequent among operators of logging machines. The ability to sit straight is what most operators point out to be the most desirable feature of the self-leveling and swiveling cab. The low noise level is also appreciated, as is the ability to swivel the cab around on its vertical axis. The swiveling ability of the cab gives better visibility and also helps reduce the amount of head rotations. Furthermore, jarring motions and extreme swing due to uneven terrain are much less bothersome than in a conventional cab design. Vibration levels at the operator's seat in the self-leveling cab are equal to those measured in conventional rigid cabs. This new cab design provides comfort to the operator and improves the operator's ability to work at a sustained high efficiency. A follow-up study conducted over several years shows that the productivity of a harvester increased by 5 to 10% after a change from a rigid to a self-leveling and swiveling cab.

Keywords: *Cab-design, ergonomics, work posture, productivity, vibrations.*

BACKGROUND AND PURPOSE

This article describes the design and ergonomic studies of a self-leveling and swiveling cab manufactured by the Swedish company Pendo AB. Details are provided of a time-study, a follow-up of machine productivity, and the options of the operators who have used the new design. Additional studies are presented that describe entering and exiting the cab, cab size, work posture, visibility, vibrations on the operator's seat, noise, and the extent of cab usage.

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Operators of forestry machines are exposed to an array of fatigue-causing factors: cab vibrations, jarring motions due to uneven terrain, uncomfortable work positions, and the constant twisting and turning of the head, neck, and cervical regions. Results of a health investigation of 1174 forest machine operators in Sweden indicated a prevailing average overload syndrome of 50%, mainly characterized by neck/shoulder complaints [3]. The pursuit of suitable technical solutions to these problems has been in the works for a number of years. Some of these solutions are cabs with better visibility, chairs with cushioned vibration, self-leveling chairs, the mounting of a bogie on both front and rear axles, split rear axles, wider tires, pendulum arms for all tires, a swiveling cab, the passive cushion of shock waves in the hydraulic system, an actively cushioning and leveling cab, and a suspended, self-leveling and swiveling cab.

Within forestry, a self-leveling and swiveling cab is a radical new innovation for the alleviation of skewed and twisted work positions. In this design the cab is suspended from an arched column that is in turn connected to a swiveling socket (Figure 1). The cab can swivel around on its vertical axis from 0° to 270° and remains vertical in terrain with a 15° slope or less. The cab's swiveling ability is controlled by the operator and is separated from the movements of the crane. This gives the operator the means with which to adjust the cab for optimum visibility at all times. The arched column has a vibration-reducing and shock-absorbing joint positioned at the seat of the beam supporting the cab (at eye level behind the operator), the purpose of which is to keep the cab on a horizontal position sideways. Above this joint is a U-shaped cab carrier beam with one shock absorbing joint at each side of the cab working to keep the cab in a horizontal position lengthwise. The stiffness of these absorbing joints can be manually adjusted from within the cab.

To reduce the amount of vertical vibrations, attempts have been made to use rubber bellows at the cab connection sites and hang the U-shaped cab carrier beam in an absorbing joint (Figure 2). The cab is intended to be mounted on new or used forestry machines. Approximately 90 cabs of this type have been produced up to mid 1997. Of these there are currently 80 mounted on harvesters and 10 on forwarders, mostly on older and renovated machines. The cost for a self-leveling cab ranges between US$15,000 and $23,000.

Figure 1. The self-leveling and swiveling cab suspended from an arched column attached to a swiveling socket.

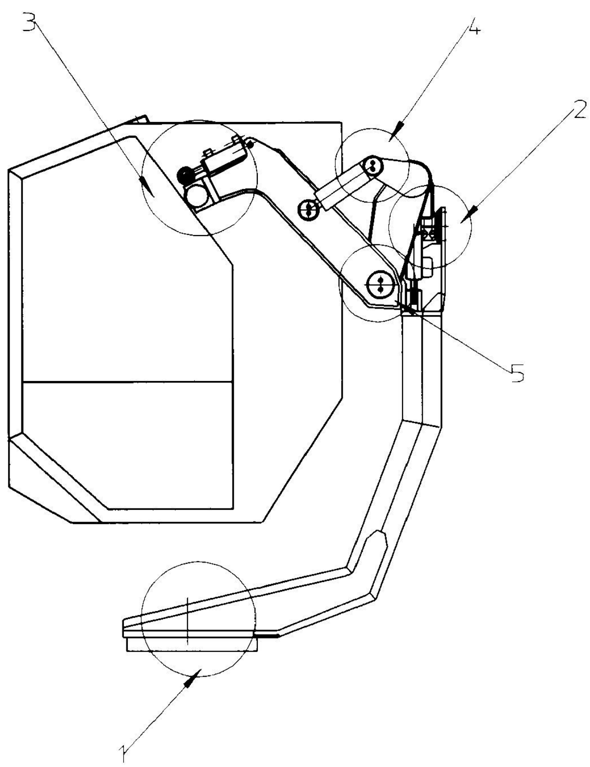

Figure 2. Sideways view of self-leveling cab: 1) Swiveling socket; 2) Sideways cushioning (y-axis); 3) Lengthwise cushioning (x-axis); 4) Horizontal cushioning (z-axis); 5) Sidebeam.

METHODS AND MATERIALS

Previous studies have been done of the self-leveling cab mounted on a number of single grip harvesters such as the FMG 250 Super Eva [4], Timberjack 1270 [6], FMG 1870 [11] Hemek EGS [9], as well as the forwarder Kockums 85-35 [5, 10].

In this study, the cab has, in most cases, been compared to conventional forestry machine cabs used in thinning and forwarding operations during normal work shifts. Thinning was carried out using the current Scandinavian short-wood system (cut-to-length system). Harvester-teams were comprised of a harverster with three alternating operators who operated machines in three-hour shifts for 12 hours a day. Forwarding was studied during normal work as well as when driving along a test track.

The program TWT [7] and a notebook computer was used in the time study. The following work elements were noted: "drive forward", "drive reverse", "crane out to the tree", "processing the tree" and "others". Operators, management and the manufacturer's representatives were all asked to answer a set of prepared questions. The "Ergonomic Checklist for Forestry Machinery" [2] was used while performing the ergonomic study. The production of an FMG 250 Super E harvester was monitored before and after the changeover to the self-leveling cab by the management from ASSIDomän Skog &Trä, Örebro forest management district.

Studies [4, 5, 6] measured whole-body vibrations in the x, y, z-directions simultaneously (WBWT according to ISO 2631/1, time-constant 1 second) and used Brüel & Kjær 2231/s, vibration-unit 2522, program BZ 7105, and seat-recorder 4322. Studies [10, 11] used the Brüel & Kjær 2512 and the seat-plate 4322. This particular equipment measures acceleration in one direction at a time only. The time-weighted noise levels, dB(A), were measured with the Brüel & Kjær 2221 noise meter with the microphone placed just above the operator's breast pocket. The operator's head movements (cervical spine rotations) were measured with a Nodmeter (jointed aluminium levers with goniometers worn by the operator).

RESULTS WITH COMMENTS

Time study and production. One hypothesis was that the work element "crane out" would be faster to perform from the new cab. The work element "crane out" took an average of 6.8 seconds to perform during thinning, using the self-leveling cab on the single grip harvester FMG 250 Super E with the crane 170 E (Table 1). At a similar first thinning the work element "crane out" took 9.6 seconds [7]. In that study the operators used the conventional cab connected to the FMG 250 harvester and the crane 374E. Please note that the 170 E crane is more powerful than the 373 E, which makes it difficult in determining what part the self-leveling cab played in reducing the time for the work element "crane out".

During the first season (1992/1993), with the self-leveling cab mounted to a FMG 250 harvester, the productivity per hour rose by as much as 25% . This increase was due to, at least, three known factors:

1. Improved operator ability during the course of the year, particulary for one inexperienced operator.

Table 1. Time study in thinning of a single grip harvester FMG 250 Super E with the mounted self-leveling cab. Work elements studied were: Driving ahead, Crane out to the tree, Felling and processing (from gripping of tree to the release of the top).

Operator	Mean diameter of the trees removed, number of stems/ha before and after thinning	No. of stems cut per minute	Driving ahead (sec)	Crane out mean (sec)	Crane out std .dev. (sec)	Felling and processing (sec)	Study time (min)
1	15.4 cm, 2000/1200	1.3	12.6	7.2	4.6	27	21
2	15.4 cm, 2000/1200	1.5	10.8	7.1	3.6	21	119
1	16.4 cm, 800/500	1.8	9.6	6.4	3.9	18	47
2	16.4 cm, 800/500	1.7	8.4	6.5	3.4	19.2	70

2. The crane itself was retrofitted with shock absorbers during the fall of 1993 which improved crane stability.

3. The change to the self-levling cab. An estimate [8] is that the new cab accounted for an approximate 5 to 10% of the productivity increase. The estimate is based on a two-year follow-up of the production of a FMG 250 Super E harvester.

Enter and exit the cab. In order for the operator to have a safe exit he/she has to turn the self-leveling cab in such a way that the door is aligned with the ladder. If not, the exit will become an unforgettable "free fall" or at best an awkward climb over machine parts. A minor imposition occurs when an operator enters the cab. First, the step up into the cab is higher than usual and in a diagonal fashion. Second, the cab rocks back when the operator sets his/her foot in the cab. A later model of the cab, with vertical cushioning, can be lowered and positioned on the swiveling socket. This allows for a safer and more secure way to enter and exit the cab.

Working position. The operator's work environment and body posture in a self-leveling cab is horizontal even when the terrain is at an incline up to 15°. The ability of the cab to swivel around its vertical axis allows the operator to position the cab so that the best possible view over the work area can be obtained. The operator is thus not exposed to the same amount of fatigue-inducing factors such as the skewed and twisted work postures that occur in a regular cab. After a few months operators using the self-leveling cab used its swiveling ability 0.8 times per tree. After two years the same figure had increased to an average of 2.3 times per tree. The swiveling ability was used while driving forward, getting in position to cut, and during felling and processing.

Operator head rotation (the cervical spine rotation) were measured and compared while using both the self-leveling cab and conventional rigid cabs (Figure 3). By mounting the self-leveling cab to the harvester Timberjack 1270 the number of head rotations beyond 22.5° had been reduced by 10 minutes per hour two weeks after delivery. As for the FMG 250 Super E, the number of head rotations beyond 22.5° was reduced by as much as 28 minutes per hour four months after the self-leveling cab was introduced.

Cab. The inside size of the self-leveling cab adheres to recommendations set forth in the "Ergonomic Checklist" [2] (Table 2). However, available leg and foot room is not sufficient for an operator of above medium height.

Table 2. The size of two different self-leveling cabs and the rigid Timberjack 1270 cab compared to recommendations laid out in the "Ergonomic checklist for forestry machinery" [2].

Point of Measurement	Self-leveling cab on FMG 250 SuperE	Self-leveling cab on Hemek EGS	Standard cab Timberjack 1270	Minimum values in Ergonomic checklist
Width [cm] (glass to glass at shoulder level)	115	118	125	90
Height [cm] (floor to ceiling in front of chair)	165	164	164	160
Length [cm] (glass to glass at elbow level)	157	143	145	130

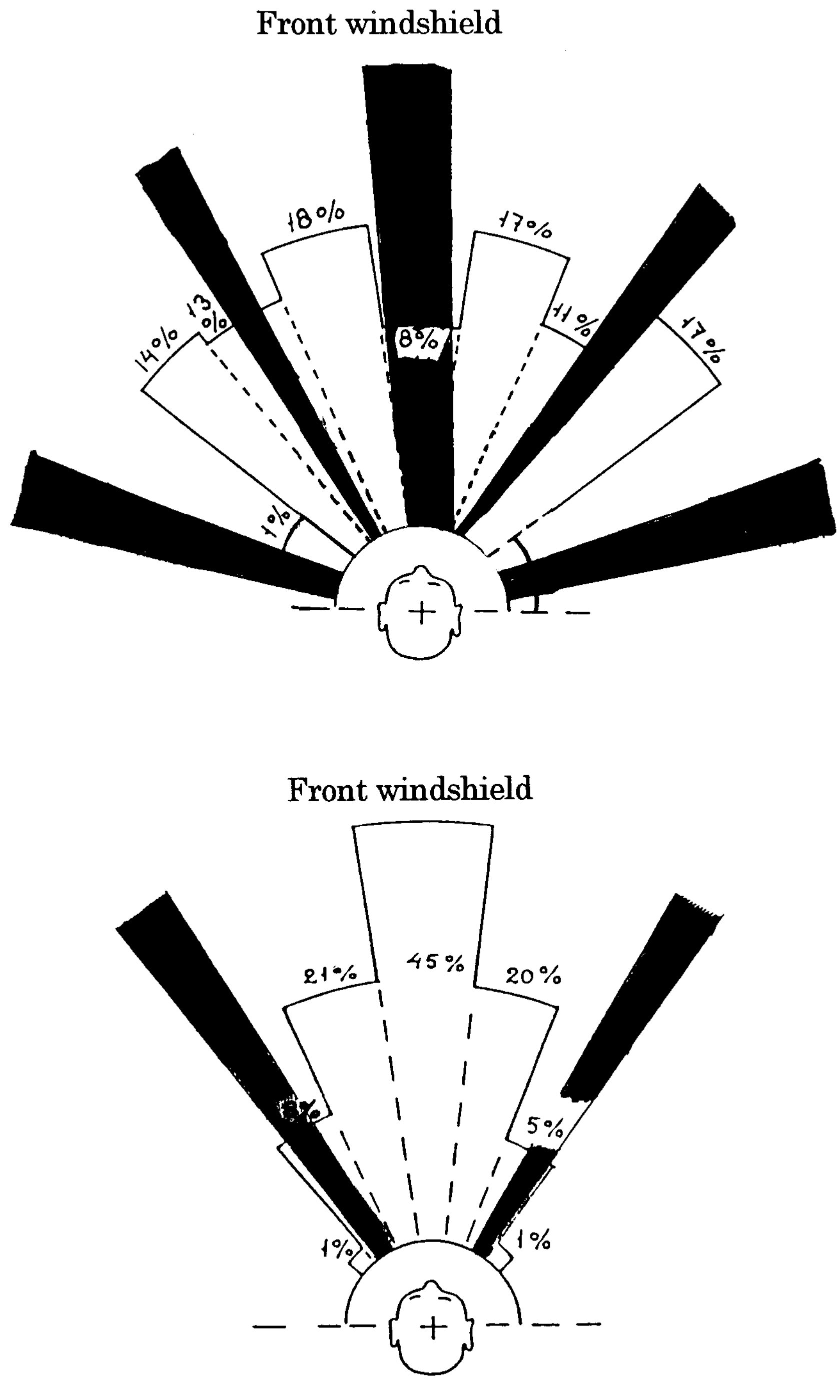

Figure 3. Distribution of operator head rotation (cervical spine rotation) within different sectors when measured with a "nodmeter" [7]. The area in each sector represents the amount of time that the head spent there. The top picture shows measurements of an operator performing a thinning from a conventional rigid cab mounted to the FMG 250 E. The bottom picture shows measurements of an operator performing the same type of thinning while in a self-leveling cab mounted to a single grip harvester FMG 250 Super E. The dark areas are restricted views.

Visibility from the cab. The self-leveling cab provides good visibility both upward and forward. Sun reflection in the windows is alleviated by turning the cab slightly to one side. The same turn applies for the windshield-wiped part of the window during rain or snow. Limbs, which have the potential to smear the windows, can be moved away by swiveling the cab. One problem, however, is that debris, snow, and ice tend to stick to the slanted window above the head of the operator. The operator's ability to see below branches in a spruce forest is not as good as in a conventional rigid cab. This is because the self-leveling cab sits higher than usual (160 cm above ground in a Timberjack 1270). This is not a problem in a pine forest where high operator level is advantageous.

Noise. Noise levels in the self-leveling cab are lower than in the two other types of cabs that were measured. The lowest measured noise level during a work shift in a self-leveling cab was 62 dB(A) and the highest 70 dB(A) (Table 3).

Vibrations. The vibration levels presented in Tables 4 and 5 show that there is no significant difference between the self-leveling cab and the conventional rigid cab regarding the vector sum of the three axes. Table 4 shows, however, that the vertical vibrations (z-axis) in the self-leveling cab, without vertical cushioning, are higher compared to the rigid cab. Table 5 shows that the cushioning of the vertical vibrations reduced the vibration level.

Ideally, vibrations should be measured during a standardized run on a widely accepted work and test track. There is, however, no such accepted standard. Measurements of vibrations that are accounted for in this study have been made on a number of different machines, with different equipment and in different terrain types, temperatures, speeds, etc.

Table 3. Noise levels in self-leveling cabs as compared to standard cabs.

Machine	Self-leveling cab [dB(A) Leq]	Standard cab [dB(A) Leq]	Comments
FMG 250 Super E	66	68–69	
FMG 1870 EGS	62	–	Engine is mounted far from cab
Timberjack 1270	63–65	70–72	
Kockums 85-35	66–70	–	Exhaust pipe very close to cab
Hemek EGS	67	–	Exhaust pipe close to cab

Table 4. Vibration levels (m/s²) on the operator's seat, as measured in a harvester using a self-leveling cab without vertical vibration cushioning compared to a conventional rigid cab (a lower value is favourable). Harvesters used were an FMG 250 Super E (A), Timberjack 1270 (B), and FMG 1870 (C).

	Thinning[1]						Final cutting[1]							Strip road drive
	Self-lev. cab on A		Conventional rigid cab on A				Self-leveling cab on B				Conventional cab on B[6]		Self-lev. cab on C	Self-lev. cab on B[7]
			2	2	3	3	4	4	5	5				
x-axis	0.14	0.11	–	–	–	–	0.18	0.20	0.20	0.15	0.21	0.22	0.11	0.23
y-axis	0.15	0.11	0.35	0.33	0.17	0.15	0.16	0.17	0.18	0.14	0.19	0.21	0.14	0.39
z-axis	0.20	0.17	0.16	0.16	0.11	0.10	0.23	0.22	0.30	0.13	0.16	0.18	0.14	0.50
Vector sum.	0.35	0.28	–	–	–	–	0.41	0.43	0.50	0.37	0.43	0.43	0.29	0.80

[1] Machine velocity in thinning and final cutting was 1.5 to 5 meters/minute.
[2] Frozen bare ground, +7°C, GSI=1,1,1 (G=Ground carrying capacity, S=Surface structure, I=Inclination [1].
[3] Snow 10 cm, +5°C, GSI=1,1,2.
[4] Snow 10 cm, -5°C, GSI=1,2,1,600 trees/ha.
[5] Snow 75 cm without frozen crust, -12°C, GSI=1,3,1, 900 trees/ha.
[6] Snow 25m, -2°C, GSI=1,3-4,2, 1600 trees/ha.
[7] Velocity 56 m/min, -5°C, GSI=1,2,1-2.

Table 5. Vibration levels during hauling along a 230-meter drive of frozen wetlands with the Kockums 85-35 forwarder at -24°C. The self-leveling cab with vertical cushioning is locked by hanging the U-shaped cab carrier beam in the absorbing joint.

	Empty						Loaded (13 m³f)					
	Self-leveling cab vertically cushioned		Self-leveling cab with locked vertical cushioning		Conventional rigid cab		Self-leveling cab vertically cushioned		Self-leveling cab with locked vertical cushioning		Conventional rigid cab	
	Velc. m/min	Vib. m/s²	Velc. m/min	Vib. m/s²	Velc., m/min	Vib. m/s²	Velc. m/min	Vib. m/s²	Velc. m/min	Vib. m/s²	Velc. m/min	Vib. m/s²
x-axis	49	0.50	52	0.47	52	0.45	49	0.40	49	0.38	51	0.42
y-axis	48	0.63	49	0.75	52	0.75	48	0.67	49	0.79	49	0.67
z-axis	49	0.42	50	0.50	52	0.447	48	0.40	48	0.50	48	0.45
Vector sum	49	1.22	50	1.35	52	1.31	48	1.17	48	1.34	49	1.20

[1]Temperature during time of measurements was -24°C, GSI=1,1–2,1 (Table 2).

Table 6. Interviews with 13 experienced operators who had used the self-leveling cab mounted either on a harvester or on a forwarder. Two of the operators using the FMG 250 harvester had been interviewed in part when the cab was new, and then again two years later. The operators of the Kochums 85-35 forwarder were interviewed in part when the vertical cushioning of the cab was carried out by using inflatable rubber bellows and in part when the cushioning was done using an accumulator connected to the cab carrier.

	Operators of harvester			Operators of forwarder, cab with vertical cushioning	
Questions	FMG 250 Super E	Timberjack 1270	Hemek EGS	Kockums 85-35, bellow	Kochums 85-35, abs joint[1]
What is it like to work in the self-leveling cab?	Good, different, revolutionary, visibility, quiet, at level, stable.	Good.	Good, easy.	Good.	Better cushioning now.
What works better than in other cabs?	Visibility, ability to sit straight, fewer head rotations.	Softer, sitting horizontally, quiet, good visibility.	Visibility, sitting straight, better work posture.	Work posture, less noise, softer.	Softer vertical and less sideways bumping.
What works less well than in other cabs?	Not enough space for feet, feet jammed[2], poor heating.	Space for feet, difficult getting in and out of the cab.	Nothing.	Crossbar to ceiling window blocks view.	Placement of controls.
What can be improved?	Available space, window wipers, heating.	Vibrations in vertical direction.	Protective ceiling-ramp (for lights).	Remove cross bar, adjust cushioning from within cab.	More grab handles for maintenance, placement of controls.
How is work efficiency and the ability to do quality work affected?	More alert, able to see rocks and stumps better, less tired.	Less tired, easier to work longer shifts.	For the better, able to work longer before I need a break.	Do not know, do not think performance is affected.	—
In what way is your health affected?	Less tense, less head-fatigue, an advantage is sitting horizontally.	Less tension in shoulders and in thumb[3].	No neck-pains right now, muscles more relaxed.	Back somewhat better, has not used the cab long enough yet.	No, does not know.
Are there any hazards associated with this cab?	Exiting the cab.	Do not know.	Entering and exiting the cab.	Entering and exiting the cab.	No.
How long did it take to get used to the cab?	3 to 4 weeks to use the swiveling ability.	More than 3 months to use the swiveling (older operator).	Do not know, only driven for a month.	1 month.	—
What do you think about the cab's future?	Prefer it during thinning, perhaps not on a forwarder.	—	There will be nothing else for harvesters.	More suitable on harvesters, but want it on forwarder as well.	Prefer it on the harvester, but works well on a forwarder too.
Is there anything you would like to add regarding the self-leveling cab?	Damn good idea! Very satisfied, feel well due to its ability to keep itself level. The swiveling is good for the yield.	To be able to sit straight is the best.	There is no better cab.	The rubber bellow should be filled just right.	Incredible visibility and low noise level, always sitting straight during loading.

[1] See Figure 2.
[2] The operator controls swivel with left foot and accelerator with right.
[3] Changed at the same time, from a hand-controlled lever to a hand-and-finger-controlled joy-stick.

DISCUSSION

What the operators appreciated most about the self-leveling and swiveling cab was the ability to sit horizontally and not have to tense up even in highly uneven terrain. The low noise level was also highly appreciated. The operators maintain the same opinions after several years of experience with the cab. Low noise levels and the ability to sit horizontally were considered beneficial for one's health. The operator's ability to swivel the cab was also noted as beneicial for production. The swiveling ability offers better visibility, which in turn speeds up the task of planning and working with the crane and the harvesting head. The amount of head rotation is greatly reduced as a result of the cabs swiveling ability, which consequently increases work pace.

Higher levels of vibrations and greater swing were concerns associated with the construction of a cab with a higher mount than the norm. However, measurements show that the self-leveling cab is under or on the same par as other conventional cabs with regards to vibrations. Bumps and jarring motions are considered to be less bothersome using the self-leveling cab. Furthermore, operators of the vertically-cushioned self-leveling cabs experienced added relief from jarring motions as well as from the swing that occurs when driving in terrain. Measurement also show that the vertical vibrations had been reduced.

The suspended cab may not be the best long-term solution. Ideally leveling should take place as low as possible, at the wheelbase/legs. However, that type of self-leveling is not fast enough by today's standards and is also more expensive.

The low noise levels occur because the cab is separated from the vehicle transmission and hydraulic components. Sound is carried through the air from the engine, mufflers, etc., and not through the frame of the machine.

The cab design still has shortcomings, such as problems when operators enter and exit and inadequate space for feet. The manufacturer is aware of the problems but has limited opportunities at present to increase foot space. One solution mentioned is removal of the air conditioning unit from beneath the operator seat, allowing the chair to be moved back a little.

This study concludes that a suspended, self-leveling and operator-controlled swiveling cab allows for an improved comfort when compared to conventional cabs. The operators are able to work longer with a sustained pace and work quality. "One tends to push the envelope just a little bit further", as one operator put it.

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