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DEVELOPMENT OF A REMOTELY OPERATED VEHICLE CAPABLE OF MOVEMENT ON MARSH TERRAINS AND RUBBLE

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Abstract. *This study consists of the development of a remotely operated vehicle to help search and rescue teams access difficult or dangerous areas in order to rescue victims of earthquakes, landslides, floods and other disasters and accidents. A review of the scientific literature as an evaluation of key disasters such as landslides, floods and structure collapses was made in attempt to define the requirements of the terrains the prototype would have to fulfill. This review also showed a variety of robots in different applications, each one with its singularity and for specific purposes. The scientific review revealed that a robot which could move sand, gravel, grass, mud, swamps, snow and flooded terrains, being able to minimally drill in order to reach trapped victims was not yet developed or could not be identified in this research. The choice was to build a screw-propelled robot with efficient locomotion on numerous surfaces, including water, based on 1963 Chrysler's Marsh Screw Amphibian, propelled by screws as the 1963 vehicle.*
Keywords: *search and rescue vehicle, screw propulsion, remotely operated vehicle, amphibious, drilling robot.*

1. INTRODUCTION

The environmental disasters affects people in different places and different conditions, this shows the need to develop devices to optimize the work of SAR (Search and Rescue) teams. The time to locate the victim represents the most important phase of the overall recovery time of a disaster area. It reduces the time span for every other phase, so the use of robots to help locate victims and evaluate structures can mitigate risks for the rescue workers and, specially, the victims, who depend on rescue workers to survive (MURPHY R., 2011). And it goes beyond the victims' survival, each single day the initial response is performed earlier, the complete recovery is shorten by 1,000 days or 3 years according to Murphy R. (2015) as shown on Fig.1.

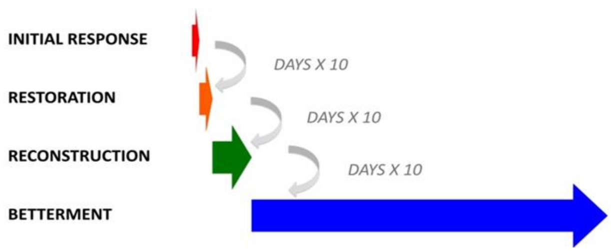

Figure 1. Days Until Full Recovery of a Disaster Area (MURPHY R., 2015)

In order to increase the victims' chances to survive, a robot capable of movement in various terrains, including underground, was thought as a plausible solution. Based on screw propelled vehicle 1963 Chrysler's Marsh Screw

Amphibian shown in figure 2 (NEUMEYER *et al*, 1963) versatile on various terrains. As its predecessor, it consists of two counter rotating rotors on each side of the vehicle, giving two degrees of freedom to the vehicle, axis X and Y. Turning is possible by applying different rotations to the rotors (FREEBERG, 2010).

A few examples of sites this robot could be used are the mining residues dam collapse in Mariana-MG, San José Mine collapse-Chile, Amatrice earthquake-Italy, nuclear plant collapse and surroundings after tsunami in Fukushima-Japan, Syrian building collapses and the rubble of the World Trade Center-USA.

2. DEVELOPMENT

The development of this vehicle consists of five main parts, problem analysis, methodology, propulsion system selection, body parts displacement and shape, dimensions and ultimately the project. The main objective is to gather knowledge through review of scientific literature and apply it to the vehicle project to allow its mobility on marsh terrains and rubble. This knowledge is important to researchers, SAR teams and product developers. The application of a vehicle like the one proposed in this article may result in the increase of the possibility of victims' survival to disasters.

After performing a research about the use of vehicles, robots and other technologies in search and rescue operations, which take place in disaster environments such as landslides, earthquakes, collapsed structures and other risk scenarios. The problem of reaching the victim seems obvious, but its solution presents a challenge to every single disaster involving trapped victims as in San José, Chile Mine accident in 2010 (GARY J., 2015), not only this, but also potential victims, as in nuclear reactor radioactive water leakage in 2011, in Fukushima, Japan 2011 (MURPHY R., 2011). In both situations, no human being was able to reach the victims underground, or inspect the structures in order to prevent further deaths.

Robotics has been of essential contribution to SAR teams worldwide, especially for the ability to reach where humans cannot. Science has offered many solutions like aerial drones, submarines, boats, walking robots, autonomous cars, but, when it comes to marsh terrains, rubble and mud, there are just a few cases of success. One of them is 1963 Chrysler's Marsh Screw Amphibian (NEUMEYER *et al*, 1963) as shown on Fig.2.

Figure 2: Marsh Screw Amphibian (NEUMEYER *et al*, 1963)

This vehicle was capable of movement on several marsh terrains, mud, snow, water and sand. It served as a guide for the project of the new vehicle.

2.1 Methodology

This study took advantage of Neumeyer's previous studies, who built a scale prototype and real size vehicle for operation in marsh terrains. The data presented on Chrysler's Marsh Screw Amphibian test report (NEUMEYER *et al*, 1963) defined the parameters for that vehicle. Such testing report, along with Freeberg (2010) dissertation, Study of Omnidirectional Quad-Screw-Drive Configurations for All-Terrain Locomotion, and Design Manual for Buoyant Screw Propulsion (NEUMEYER *et al*, 1965) are the scientific basis for the prototype's project. Future testing is intended to deliver useful data in comparison with Marsh Screw Amphibian and Quad-Screw-Drive Omnidirectional vehicle. This project was developed in CAD software, 3D Printed and assembled in the Newton Paiva's FabLab.

2.2 Locomotion System Selection

The research on most successful robots and vehicles, demonstrated that each of these robots have a locomotion system designed for specific purposes.

Wheels are the most common method of locomotion present in vehicles, better applied to flat surfaces. Every deformation on the surface requires complex suspension systems and multiple wheels drive, as seen on Fig.3.

Figure 3: Wheel tractor on the mud in disaster area (CRISTOPHE SIMON, 2016).

Track Drive, Track Laying or Crawler, would not be fit for underground use, because each side of the crawler provides traction in a different direction. So, in order to use it, there should be multiple tracks around the vehicle, so every surface would provide traction in the same direction. This implies more components, higher costs, higher complexity and possibly higher weight. It is applied in heavy weight vehicles, such as construction vehicles and war tanks. Fig. 4.

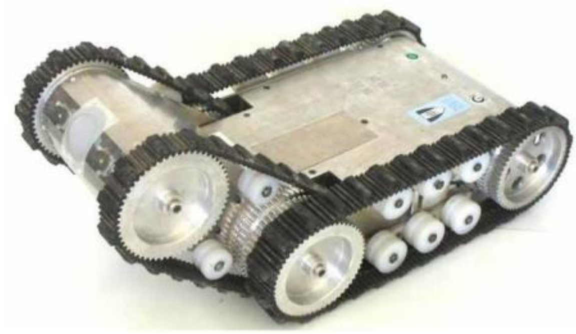

Figure 4: Raposa SAR Robot (FRAZÃO et al., 2005).

Legs are efficient and offer the possibility of jumping, but they require a complex control system, are hard to build and extremely expensive. This kind of propulsion system is mostly applied in forests and urban environments, dry and rigid terrains with obstacles. Fig. 5.

Figure 5: Spot legged Robot (BOSTON DYNAMICS, 2017)

Snake movement, Fig. 6, is mostly applied in SAR Robots, are as efficient as a snake itself, also in moving through rubble and underwater, involves a complex assembly and control system. It can overcame tiny spaces like tunnels and spaces between rubble.

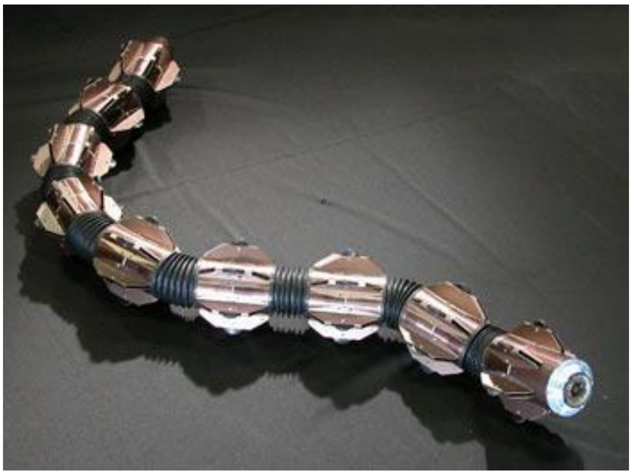

Figure 6: ACM R5 Snake Robot (HIROSE SHIGEO, 2015)

Screw locomotion, as shown on Fig. 7, the same principle present on power screws as machine elements, is able to deliver traction with the whole surface of the blades, which is useful when the vehicle is surrounded by soil, snow or mud, and it provides a drilling capacity to the vehicle. The prototype is intended to be able to move through rubble, and such capacity is important to open spaces already present between the grains.

Figure 7: Afeka Digger Robot (AFEKA, 2014)

After the review of land propulsion systems, the screw drive propulsion was found to be the most fit for the prototype, presenting simple construction, robust, cheap and efficient in underground environments, rubble, mud and water. Following the proved efficiency of the Marsh Screw Amphibian (NEUMEYER *et al*, 1963), the prototype will use Screw Drive Propulsion to move on different types of terrain.

2.3 Body Displacement and Elements

All shapes in the prototype are thought to penetrate the ground, based on the principles of fluid dynamics, noticed on the equation Eq. (1) of the Drag force:

$$F_D = \frac{1}{2} \rho C_D v^2 A \quad (1)$$

Where F_D is the resultant drag force, ρ is the density, C_D is the drag coefficient, v is the speed of the object relative to the fluid and A is the cross sectional area. Considering the fact that the only variables that belong to the project itself are the drag coefficient, defined by the shape of the object, and its cross sectional area, the shapes, in the sides of the prototype penetrating the ground, are intended to have the smaller drag coefficient as possible and reduced cross sectional area.

Another aspect of the prototype in contrast with the Marsh Screw Amphibian is the centered body, with lower center of gravity, allowing it to roll and have traction upside down, as shown on Fig. 8 and Fig. 9.

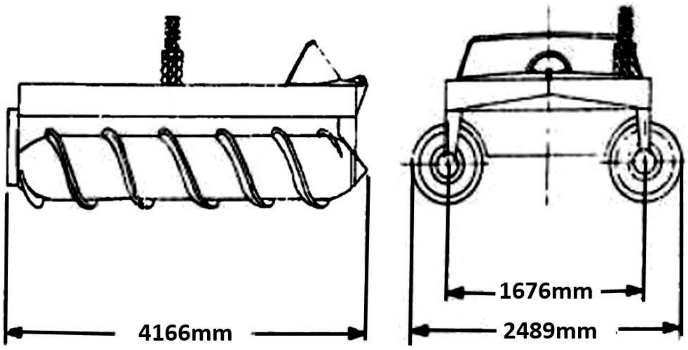

Figure 8: Marsh Screw Amphibian Overall Dimensions (FREEBERG, 2010)

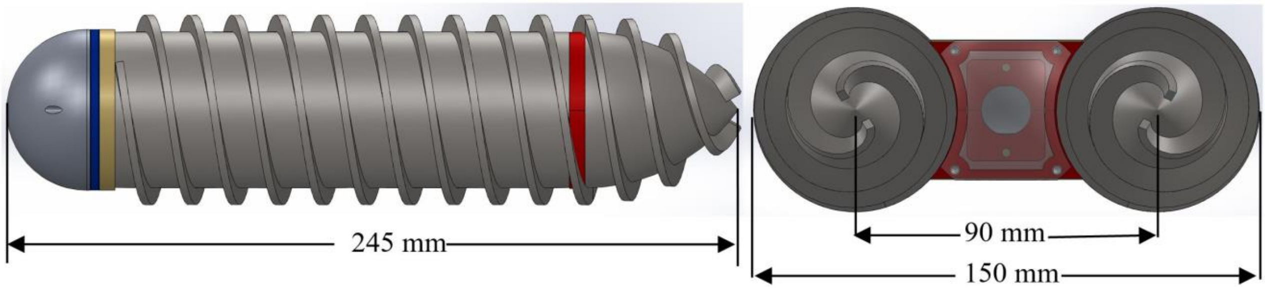

Figure 9: Prototype Overall Dimensions

2.4 Dimensions

The dimensions selection presented infinite options, this complex problem was solved aiming to adequate the component dimension to the new robot. The motors, essential items to the project, have their size defined by the manufacturer, and was chosen as referential. In other words, the rotors have to be large enough to house a 12 Volts Continuous Current (CC) of 37mm of diameter. Small as necessary to move through spaces between rocks inside the rubble. Every dimension followed the scale proportion of the Marsh Screw Amphibian. So that the largest dimension of the prototype would be 210mm, the largest 3D printing envelope 210x210x205mm.

For this reason, choosing the length (front to back) as the largest dimension (Fig. 8) of Neumeyer's vehicle, 13 feet and 8 inches, or 4166mm were converted into 200mm, resulting in a scale of approximately 23:1. The distance between the rotors axis is 74mm, to maintain turning radius capabilities. To allow the buoyancy, the components should be watertight, so the movement over water is possible. Overall dimensions are 200x130x62 mm (Length x Width x Height).

The Screw Drive locomotion system follows the parameters established by Neumeyer *et al* (1965) and Freeberg (2010) as seen on Fig. 10 and Tab. 1.

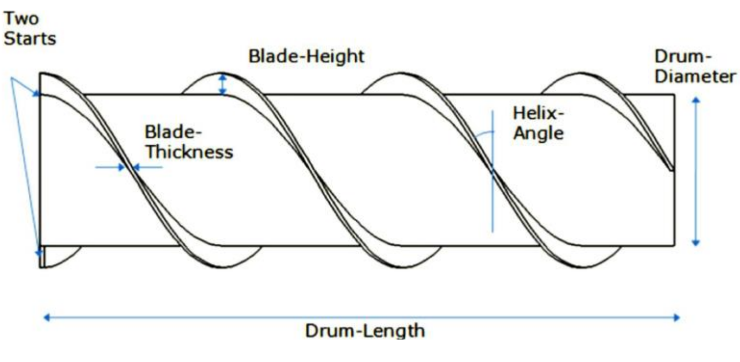

Figure 10: Screw Parameters (Freeberg, 2010)

Table 1. Screw Parameters Established by Neuemeyer et al (1965)

Component	Marsh Screw Amphibian	Prototype
Rotor(s) Length	4540mm	200mm
Rotor Diameter	660,4mm	50mm
Number of Blade Starts	2	2
Blade Height	177,8mm	6,25mm
Blade Thickness	12,7mm	2,5mm
Helix Angle	32°	30º

These parameters, according to Neumeyer *et al* (1965) Design Manual for Buoyant Screw Propulsion, are the most efficient when applied to different types of terrains. Although the ideal scale is 22,685:1, in some cases, dimensions had to be changed, to comply with the 3D printing envelope and Motor diameters, the size limits to the project.

The standards defined in the work of Freeberg (2010) contain information about Helix Angle, there were tests ranged from 20° to 50°, the average angle ideal for minimizing slippage in all terrain setting was 30°.

Blade Height to Drum Diameter Ratio, also expressed in Freeberg (2010) work is 0,375, though, Chrysler also tested 0,125. 0,167 and 0,208 ratios.

2.5 Project

The project of the prototype was developed with Dassault's SolidWorks 3D CAD Software 2016®, what made possible to preview the assembly. The shape of the rotors are intended to reduce the Drag Coefficient (C_D), so they are shaped as a screw. The helix follows the rotor surface to avoid discontinuities, including the curve point. The components, displacement, mass and printing time are described on Fig. 11 and Tab. 2.

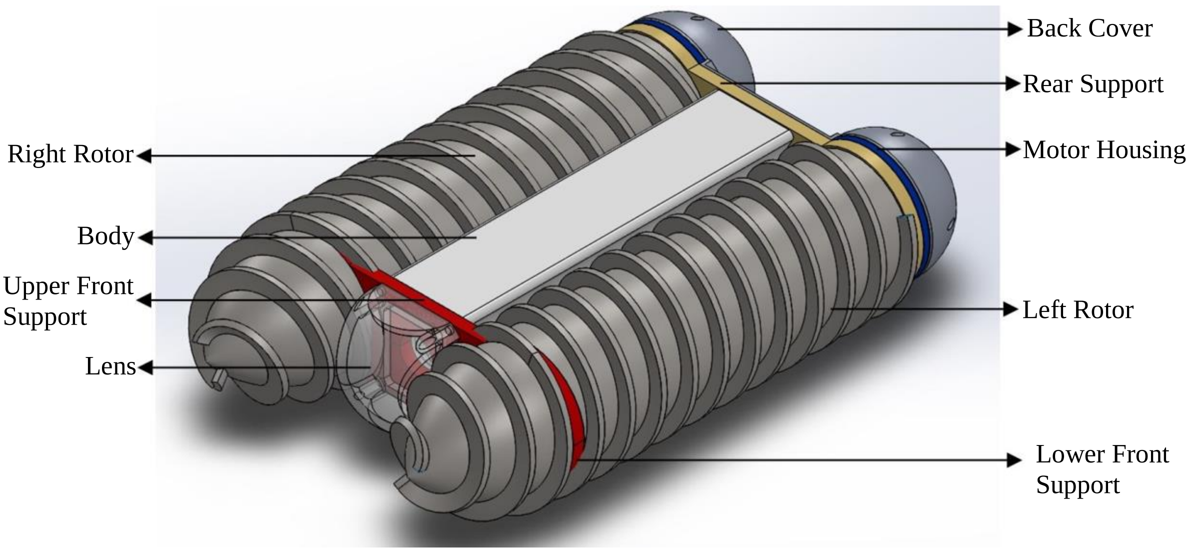

Figure 11: Prototype's Isometric View

Table 2: Prototypes Components

Item	Component	Qty	PLA mass(g)	Printing Time (min)
1	Motor Axis-Rotor Coupling	2	10	27
2	Front Support	2	20	138
3	Rear Support	1	20	139
4	Motor Housing	2	80	201
5	Clockwise Rotor	1	200	1052
6	Counterclockwise Rotor	1	200	1052
7	Lens	1	30	146
8	Back Cover	1	80	215
9	Body	1	50	244
Total		12	690	3214

The rotors are counter-rotating, the right rotor spins clockwise while the left rotor spins counterclockwise in order to move forward. Reward movement is made with R rotor spinning counterclockwise and L rotor spinning clockwise. Simple Turning is done by spinning only one of the rotors, but different combinations of Rotations between the rotors also result in turning. If both rotors are spinned in the same direction, the prototype moves sideways.

The motors are two Neoyama S/N AK555/390ML12S18200C, capable of delivering a Torque of 0.12748645 N.m on start, 12 Volts and 6,8 Amperes at maximum efficiency. Fig. 12.

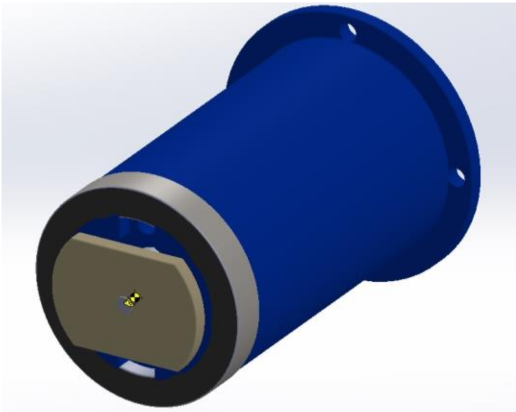

Figure 12: Neoyama Motor Assembly with Housing, Coupling and Watertight Bearing

2.6 Manufacturing and Assembly

The manufacturing process complied of two main stages, printing and assembly. All the printing was performed in the Ultimaker 2 3D printer, as depicted on Fig. 13. The 3D printing left chip and burr, what required a finishing process before the assembly, as seen on Fig. 14.

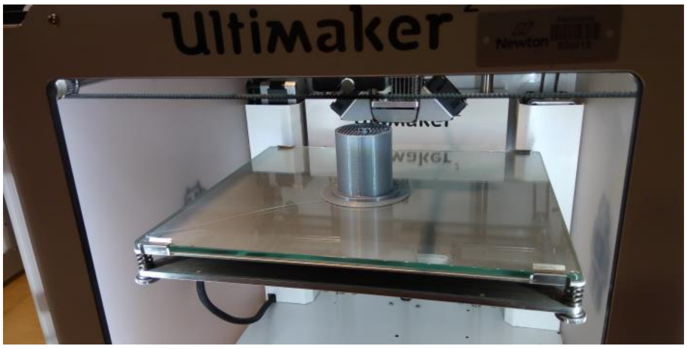

Figure 13: Motor Housing Printing Proccess.

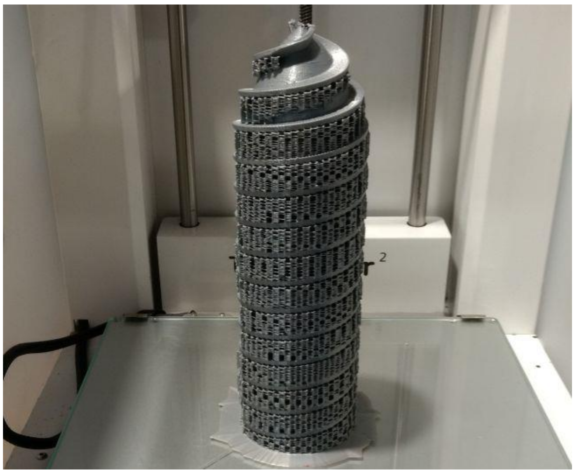

Figure 14: 3D printed Rotor with burr left from the Printing support process.

The prototype was assembled by hand with the wiring, as shown on Fig. 15. The control was made using two Double Pole Double Throw Switch (DPDT), capable of reversing polarity to the motors, thus reversing rotation direction. All components are shown on Fig. 16.

Figure 15: Prototype Assembly Proccess

Figure 16: Prototypes Components

3. RESULTS

The assembly was made, and then prototype tested. Approximately five seconds after motors started, the PLA (polylactic acid polymer) coupling melted in the inner bore as seen on Fig. 17. The reasons will be investigated and brass couplers are being produced. With the Brass Couplers assembled, the trafficability tests will be performed and the Prototype Speeds on different terrains and turning radius will be compared to Chrysler's Marsh Screw Amphibian. The whole prototype assembly, including control and power source can be seen on Fig. 18.

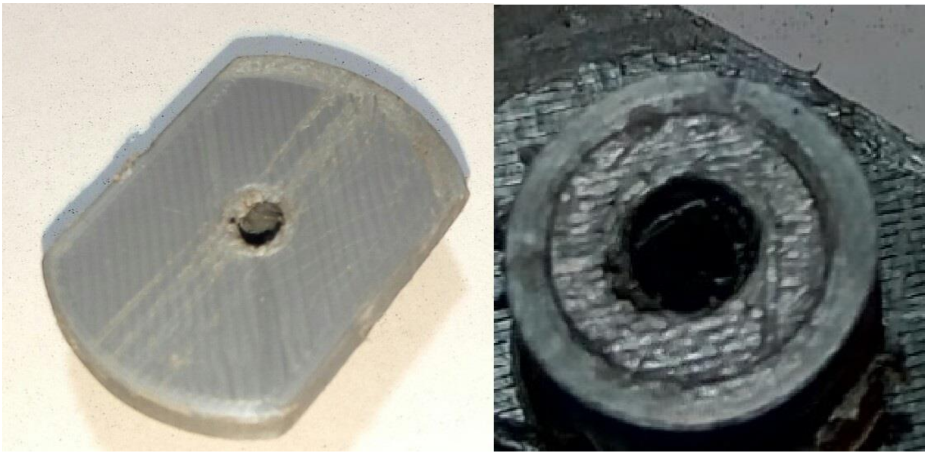

Figure 17: Inner Bore Melt

Figure 18: Prototype's full assembly

4. CONCLUSION

The review of scientific literature, the study of the applicability of SAR robots to rescue victims and shorten the time needed for disasters areas full recovery, or even the use of such robots to inspect structures in engineering business, revealed that the use of robots is much below the potential. After the Mariana-Brazil tailings dam collapsed, firefighters were shown on TV crawling over the tailings mud. The reality is that Brazil, a continental size giant in South America didn't have a suitable vehicle for immediate use. During this work, many disasters took place in different parts of the globe, and in most of them, rescue teams relied in their training and dogs. These robots are able of carrying devices like water and air hoses, life form detectors, cameras and thermal sensors, Carbon Dioxide (CO_2) detectors, microphones, speakers and others. Many of the dead victims could have survived in case this robots and underground life detection technologies were used.

The study of SAR vehicles have to be a priority in scientific research and development to save more lives and make economies less fragile to natural disasters, but not limited to SAR, as the applications of such vehicles are uncountable.

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