KTH - MG2040

Project Report

Table Fan

Group A

Tilda Björklund, Mustafa Genc, Tomás Homolka,
Shankar Narshi, Gabriel Nylöf, Ylva Marie Reinhold

Table of Contents

1. Introduction

Considering the assembly process during product development increases the likelihood of achieving higher product quality, lower manufacturing and assembly costs, shorter lead times, and overall improved efficiency. While the importance of efficient production has been recognized since the Industrial Revolution, the formal concepts of Design for Assembly (DFA) and Design for Manufacturing (DFM) began gaining significant traction in the 1980s. During this period, various tools and software solutions were introduced to support the implementation of these principles in industrial practice. [1]

When evaluating and analyzing an assembly process, several key factors must be considered. These include the product design, particularly its suitability for efficient assembly (taking concept like DFA and DFM into consideration), the sequence of assembly operations, and the layout of the assembly line or workstation to ensure optimal flow and minimal waste. It is also essential to assess whether each part of the process should be automated or handled manually, based on factors like complexity, cost, volume, and labor availability. Additional considerations include ergonomics and worker safety, cycle time, production cost, and quality control mechanisms to ensure consistent product standards.[2]

This report presents the results of an analysis focused on the assembly process of a table fan. By applying relevant concepts and methods related to assembly optimization, several practical improvements were identified, along with a clearer understanding of the critical components and problem areas within the current design. Using Design for Assembly (DFA) principles, recommendations were developed to simplify the assembly process and reduce both time and cost. Additionally, the creation of assembly models such as CAD files and Liaison Diagrams provided a clearer overview of part relationships and connection points. Finally, by examining the overall assembly system design and conducting a financial analysis, further insights were gained into the feasibility and cost-effectiveness of the proposed improvements.

1.1 Product description

The product analyzed in this project is a 23 cm tall table fan, sold by Biltema (Biltema, 2025), see Figure 1. This product is a budget product with a B2C cost of 149 SEK. [3]. The table fan is compact, electrically powered, and intended for personal use indoors. This fan has two propeller frequency options and it enables adjusting whether the fan head should rotate or not. This product was considered suitable for the project due to its relatively simple mechanical construction and clear part relationships. Its assembly involves typical operations such as fastening, alignment, and the integration of sub-assemblies. These characteristics make it a practical example for studying assembly sequences, constructing a precedence diagram, and evaluating basic line balancing in a structured yet accessible way.

Figure 1 - Table fan (Biltema, 2025)

The table fan is composed of several key components that work together to ensure proper functionality and user safety. These include the motor housing, control buttons, a stable base, fan blades, a front and rear protective grille, and a tilt-adjustable head. A visual representation of these components can be found in Figures 2, 3, 4, and 5.

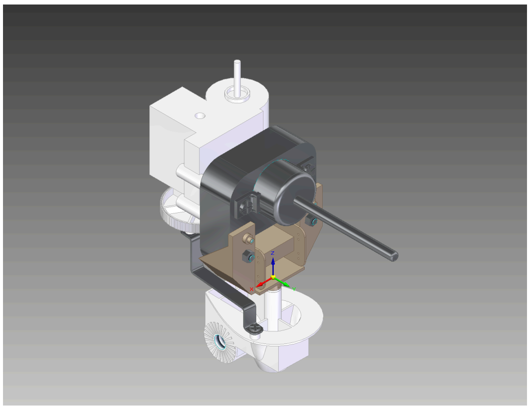


Figure 2 -Motor housing with head tilter

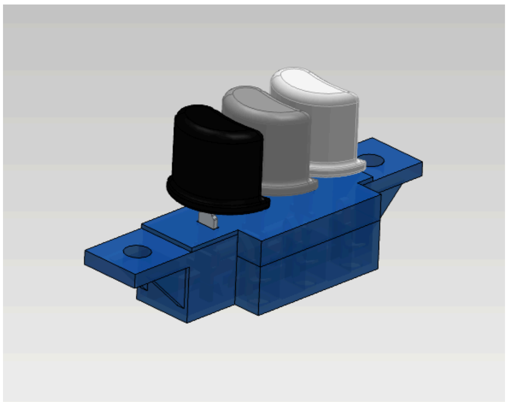


Figure 3 - Buttons

FIgure 4- Fan head with protective grills

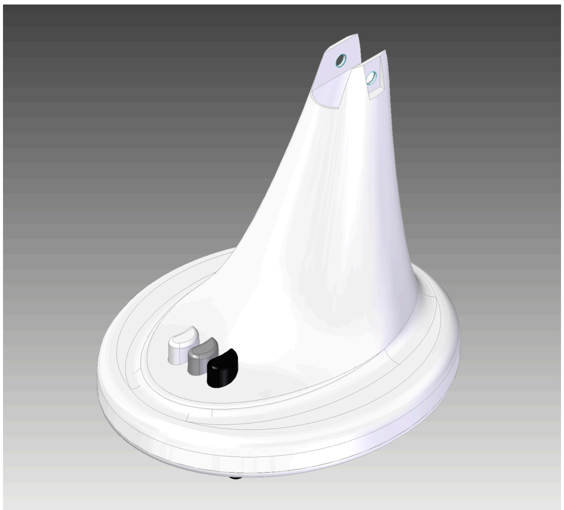


Figure 5- Stand (base)

2. Product Description and Representation

This chapter presents both the physical breakdown and the visual representation of the selected table fan. It begins with the Bill of Materials (BOM), which provides a summary of all components. Following this, a detailed part list offers a summary of all components used in the product, including part names, quantities, and corresponding identification codes. Each component is described with information such as material, dimensions, function, and symmetry characteristics, which are essential for subsequent assembly analysis. The chapter also includes product representation in the form of 3D CAD models. An exploded view illustrates the overall assembly structure and sequence. Additionally a part classification or coding system is used to ensure clarity and consistency throughout the documentation. Cross-referenced views are included to support layout planning and to connect individual components with their positions in the complete assembly.

2.1 Bill of Materials (BOM)

The Bill of Materials provides a general overview of all the components in the table fan and divides them clearly into four different sub-assemblies. Figure 6 shows the classification of Fan into Stand, Buttons, Head and Motor.

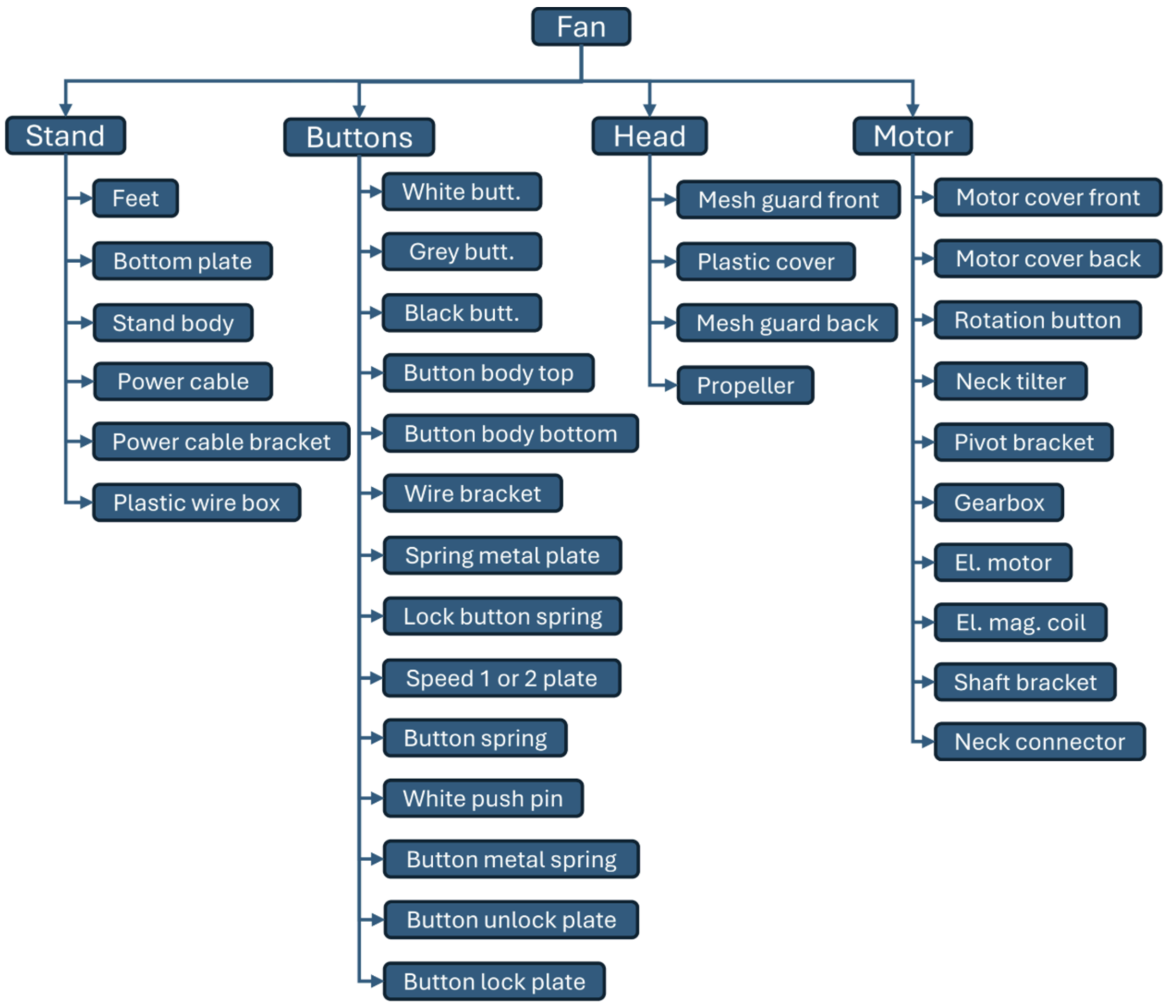
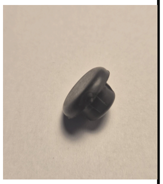


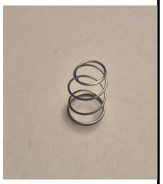
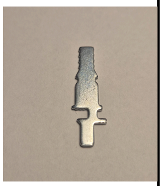
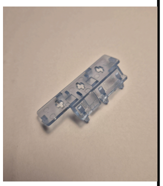
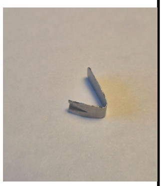
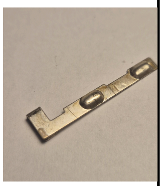
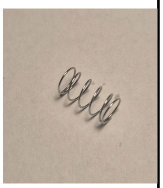
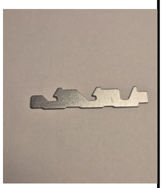
Figure 6 - Bill of Materials

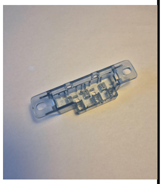
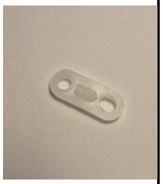
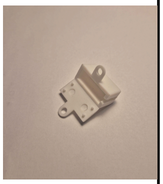
2.2 Parts List and Functionality

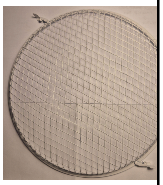
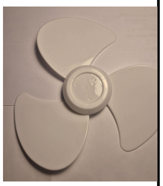
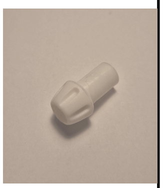
The following section presents a parts list for the table fan. Each component is listed with its part number, the sub-assembly it belongs to, a descriptive name, an image for visual reference, the quantity used, and a brief description of its function, see Table 1.

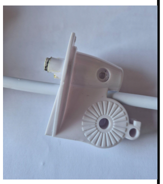
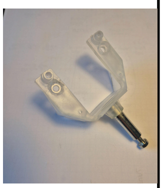
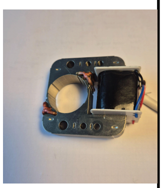
Table 1: Parts List and Functionality

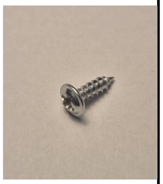
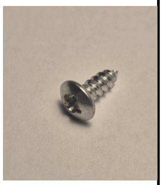
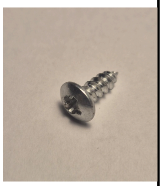
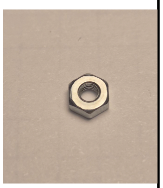
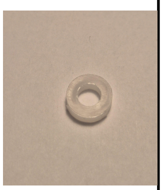
Part Number	Sub-Assembly	Name	Picture	Amount	Function	Structured Justifications
101	Stand	Feet		6	Cover screws (X03) and fan stands on them	Protects internal components or conceals parts for safety/aesthetics.
102	Stand	Bottom plate		1	Covers the inside of the stand	Protects internal components or conceals parts for safety/aesthetics.
103	Buttons	White button		1	Turns off fan	Supports functional integration in the assembly.
104	Buttons	Grey button		1	Turns on fan speed 1	Supports functional integration in the assembly.
105	Buttons	Black button		1	Turns on fan speed 2	Supports functional integration in the assembly
106	Buttons	White push pin		2	Connects button circuit	Facilitates connection between functional elements.

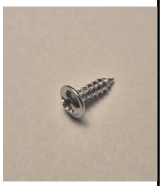
Part Number	Sub-Assembly	Name	Picture	Amount	Function	Structured Justifications
107	Buttons	Button spring		3	Keeps button under tension	Supports functional integration in the assembly
108	Buttons	Button metal plate		3	Moves white push pin (106) when button is pressed	Supports functional integration in the assembly.
109	Buttons	Button body top		1	Part of button assembly housing	Supports functional integration in the assembly
110	Buttons	Spring metal plate		2	Connects electric circuit	Facilitates connection between functional elements
111	Buttons	Wire bracket		2	Hold wire in place	Provides mechanical fastening or structural stability.
112	Buttons	Speed 1 or 2 plate		1	Connects circuit to speed 1 or 2	Facilitates connection between functional elements.
113	Buttons	Lock button spring		1	Keeps button lock under tension	Supports functional integration in the assembly.
114	Buttons	Button lock plate		1	Keeps speed 1 or 2 selected	Supports functional integration in the assembly.

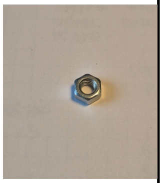
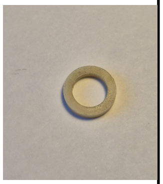
Part Number	Sub-Assembly	Name	Picture	Amount	Function	Structured Justifications
115	Buttons	Button unlock plate		1	Unlocks speed 1 or 2	Supports functional integration in the assembly.
116	Buttons	Button body bottom		1	Part of button assembly housing	Supports functional integration in the assembly.
117	Stand	Power cable bracket		1	Holds power cable in place	Provides mechanical fastening or structural stability.
118	Stand	Plastic wire box		1	Hides wire connection	Facilitates connection between functional elements.
119	Stand	Power cable		1	Powers the fan	Supports functional integration in the assembly.
120	Stand	Stand body		1	Supports fan head	Provides stability or alignment to maintain proper function.
201	Head	Plastic cover		1	Covers center of mesh guard front (202)	Protects internal components or conceals parts for safety/aesthetics.

Part Number	Sub-Assembly	Name	Picture	Amount	Function	Structured Justifications
202	Head	Mesh guard front		1	Covers propeller	Protects internal components or conceals parts for safety/aesthetics.
203	Head	Propeller		1	Blows air	Supports functional integration in the assembly.
204	Head	Mesh guard back		1	Covers propeller	Protects internal components or conceals parts for safety/aesthetics.
205	Motor	Rotation button		1	Locks fan rotation	Supports functional integration in the assembly
206	Motor	Motor cover front		1	Covers motor	Protects internal components or conceals parts for safety/aesthetics.
207	Motor	Motor cover back		1	Covers motor	Protects internal components or conceals parts for safety/aesthetics.
208	Motor	Pivot bracket		1	Turns the fan around	Supports functional integration in the assembly.

Part Number	*Sub-Assembly*	*Name*	*Picture*	*Amount*	*Function*	*Structured Justifications*
209	Motor	Neck tilter		1	Allows up and down tilt	Supports functional integration in the assembly.
210	Motor	Gearbox		1	Engages the fan rotation	Supports functional integration in the assembly.
211	Motor	Shaft bracket		2	Holds rotor shaft centered	Provides mechanical fastening or structural stability.
212	Motor	Electric rotor		1	Spins the shaft and propeller	Supports functional integration in the assembly.
213	Motor	Neck connecto r		1	Connects electric motor to neck tilter	Facilitates connection between functional elements.
214	Motor	El. mag. Coil		1	Convert electrical E to mechanical E	Supports functional integration in the assembly.
X01	Fastener	Screw M9x33		1	Holds head and stand together	Provides mechanical fastening or structural stability.
X02	Fastener	Nut 10mm		1	Holds X01 in place	Provides mechanical fastening or structural stability.

Part Number	*Sub-Assembly*	*Name*	*Picture*	*Amount*	*Function*	*Structured Justifications*
X03	Fastener	Screw M6x12		6	Holds bottom plate (102) of stand in place	Provides mechanical fastening or structural stability.
X04	Fastener	Screw M7x12		2	Holds buttons assembly in place	Provides mechanical fastening or structural stability.
X05	Fastener	Screw M7x12		2	Holds power cable bracket	Provides mechanical fastening or structural stability.
X06	Fastener	Screw M6x8		1	Closes ground box	Provides mechanical fastening or structural stability.
X07	Fastener	Screw M4x11		1	Holds mesh guard together	Provides mechanical fastening or structural stability.
X08	Fastener	Nut 5mm		1	Holds X06 in place	Supports functional integration in the assembly.
X09	Fastener	Screw M8x8		3	Holds plastic cover (201) in place	Provides mechanical fastening or structural stability.
X10	Fastener	Spacer 12mm		3	Supports X08 screws	Provides mechanical fastening or structural stability.

Part Number	Sub-Assembly	Name	Picture	Amount	Function	Structured Justifications
X11	Fastener	Plastic nut 40mm		1	Holds mesh guard back (204) in place	Provides mechanical fastening or structural stability.
X12	Fastener	Screw M6x12		1	Holds rotation button (205) in place	Provides stability or alignment to maintain proper function.
X13	Fastener	Screw M7x21		2	Holds motor cover front (206)	Provides mechanical fastening or structural stability.
X14	Fastener	Screw M7x13		1	Holds motor cover back (207)	Provides mechanical fastening or structural stability.
X15	Fastener	Screw M6x12		1	Holds neck tilter in place	Provides mechanical fastening or structural stability.
X16	Fastener	Screw M10x12		1	Holds pivot bracket and gearbox	Provides mechanical fastening or structural stability.
X17	Fastener	Black spacer		1	Spacer between X15 and pivot bracket	Provides mechanical fastening or structural stability.
X18	Fastener	Screw M10x12		1	Holds pivot bracket to neck tilter	Supports functional integration in the assembly.

Part Number	Sub-Assembly	Name	Picture	Amount	Function	Structured Justifications
X19	Fastener	Black spacer		1	Spacer between X17 and pivot bracket	Supports functional integration in the assembly.
X20	Fastener	Screw M6x35		2	Holds gearbox in place	Provides mechanical fastening or structural stability.
X21	Fastener	Screw M6x27		2	Holds neck connector to motor	Provides mechanical fastening or structural stability.
X22	Fastener	Nut 7mm		2	Holds X20 in place	Provides mechanical fastening or structural stability.
X23	Fastener	Plastic spacer 12mm		1	Spacer between neck connector and neck tilter	Provides mechanical fastening or structural stability.

2.3 Parts Specification

This section presents the physical specifications of each component, including dimensions, thickness, weight, and symmetry. These attributes are key factors affecting handling time and must be considered when evaluating assembly approaches. Understanding these factors supports more accurate planning of assembly operations and workstation design.

Table 2: Parts Specification

Part Number	α (θ)	β (θ)	TAS (θ)	Size (mm)	Thickness (mm)	Weight (g)
101	360	0	360	13	7	<1
102	360	360	720	205	10	37
103	360	360	720	21	16	2

Part Number	α (θ)	β (θ)	TAS (θ)	Size (mm)	Thickness (mm)	Weight (g)
104	360	360	720	21	16	2
105	360	360	720	21	16	2
106	360	360	720	11	5	<1
107	360	0	360	17	4,5	<1
108	360	360	720	33	1	4
109	360	360	720	54	15	<1
110	360	360	720	12	4	<1
111	360	360	720	8	3	<1
112	360	360	720	34	2	<1
113	180	0	180	11	3	<1
114	360	360	720	46	1	4
115	360	180	540	15	1	1
116	360	360	720	84	16	4
117	360	180	540	21	7	1
118	0	0	0	25	20	4
119	0	0	0	2000	13	70
120	360	360	720	250	170	85
201	360	0	360	100	10	15
202	360	360	720	270	30	132
203	360	0	360	210	220	45
204	360	360	720	270	35	140
205	360	0	360	25	10	2
206	360	360	720	210	40	18
207	360	360	720	115	110	37
208	360	360	720	70	21	6
209	360	360	720	60	52	20
210	360	360	720	70	56	42
211	360	180	540	56	13	7

Part Number	α (θ)	β (θ)	TAS (θ)	Size (mm)	Thickness (mm)	Weight (g)
212	360	0	360	130	30	90
213	360	360	720	90	33	23
214	360	360	720	75	36	336
X01	360	0	360	33	4,5	6,5
X02	180	0	180	10	3	2,5
X03	360	0	360	12	3,5	2
X04	360	0	360	12	3,5	2
X05	360	0	360	12	3,5	2
X06	360	0	360	8	3	2
X07	360	0	360	11	2	<1
X08	180	0	180	5	2	<1
X09	360	0	360	8	4	<1
X10	180	0	180	12	3	<1
X11	360	0	360	40	12	3
X12	360	0	360	12	3	2
X13	360	0	360	21	3,5	3
X14	360	0	360	13	3,5	2
X15	360	0	360	12	3	2
X16	360	0	360	12	5	2
X17	180	0	180	10	<1	<1
X18	360	0	360	12	5	2
X19	180	0	180	10	<1	<1
X20	360	0	360	35	3	3
X21	360	0	360	27	3	2
X22	180	0	180	7	3	<1
X23	180	0	180	12	2	<1

2.4 Parts Coding System

To ensure clarity and consistency throughout the documentation and analysis, a simple three-digit coding system has been applied to label all 57 components of the table fan. The system is structured according to the product's two main assemblies:

1. Stand and Head (including motor housing and buttons)
2. Fasteners

Parts belonging to the stand assembly are labeled with codes beginning with the digit 1, followed by a two-digit sequential number ranging from 101 to 120. Components of the head assembly follow the same format but begin with the digit 2, with codes ranging from 201 to 214. Fasteners are categorized separately using the prefix X, followed by a two-digit number from X01 to X23.

This coding system supports quick identification of parts based on their assembly location and simplifies cross-referencing across the BOM, CAD models, and assembly sequence analysis.

2.5 CAD models

A detailed CAD model was created for each component and assembled to mirror the current product, providing a comprehensive view of how each part and sub-assembly is designed, related, and integrated. Once the digital twin was completed, an analysis was conducted to determine the number of axes required for assembly.

The fully assembled table fan is shown in Figure 7. Figure 8, 9 and 10 is displaying how

Figure 7 - Table fan

Figure 8 - Back view of when fan head and stand disassembled

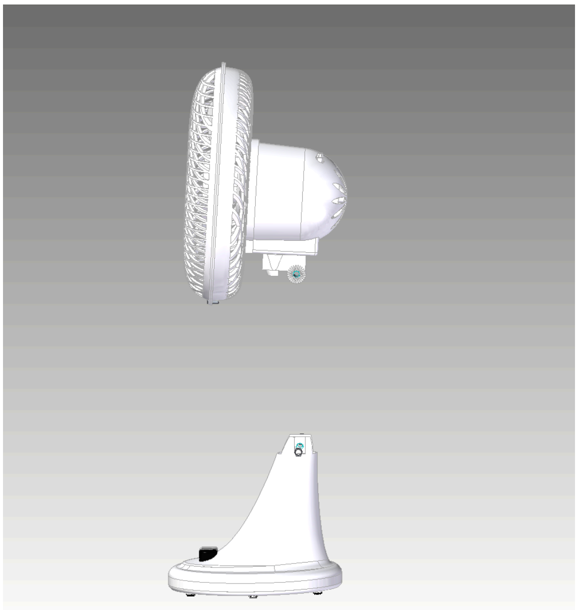


Figure 9 - Side view of when fan head and stand disassembled

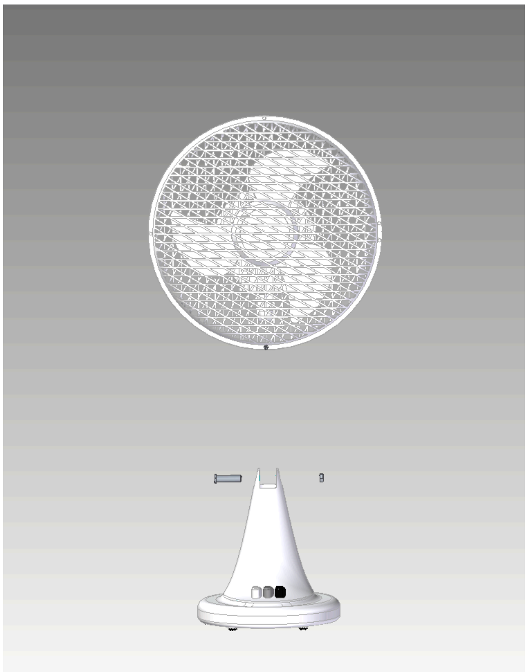


Figure 10 - Front view of when fan head and stand disassembled

Button sub-assembly

The button sub-assembly comprises several small, uniquely designed components, as illustrated in the exploded view. This sub-assembly enables two key functions:

1. Toggling the fan blade speed between two settings
2. Controlling the power state (on/off) of the fan

The three buttons seen in Figure 11 makes it possible for the user to switch between the different speed settings. To achieve these functions, the assembly incorporates multiple miniature mechanical and electrical elements that facilitate motion and enable the connection and disconnection of the circuit as required, see Figure 12. Figure 13 shows the bottom view of the button sub-assembly. There are three holes in the bottom, these allow insertion of three electric cables to close the circuit.

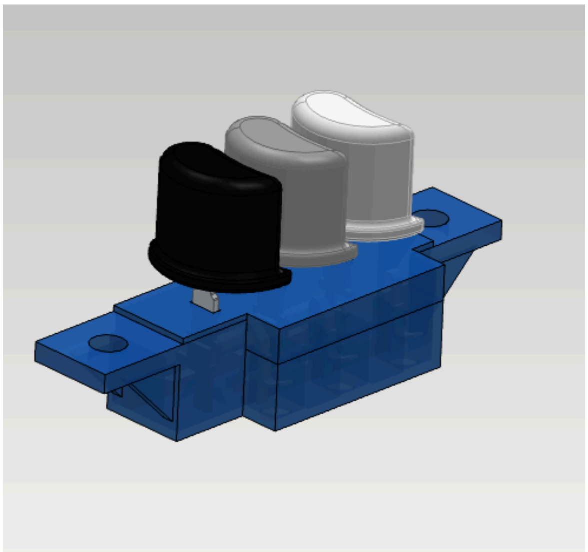


Figure 11 - Iso view button sub-assembly

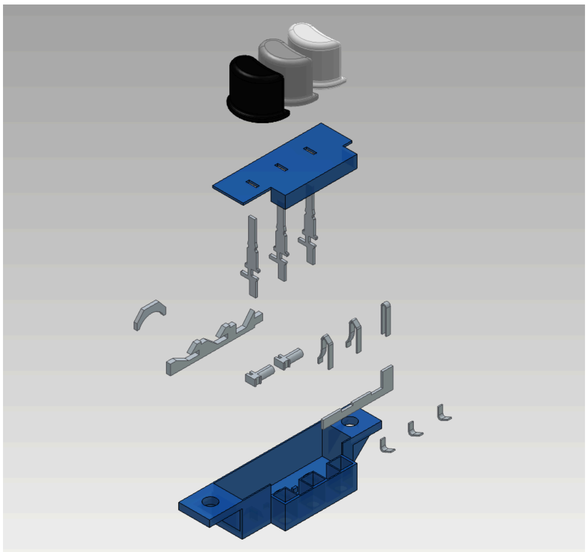


Figure 12 - Exploded view Button sub-assembly

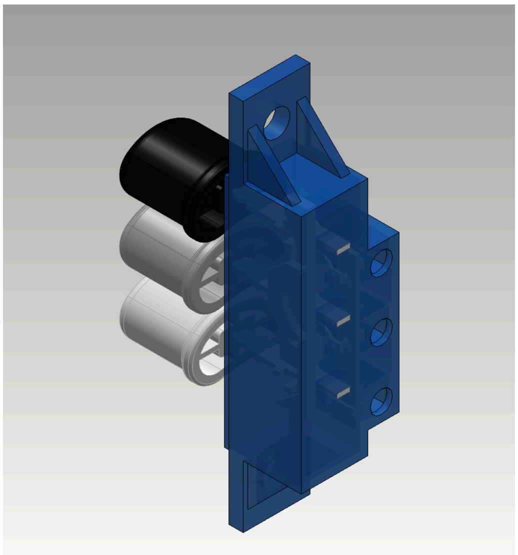


Figure 13- Bottom of button sub-assembly

The button sub-assembly has a bottom body from which all other parts are fastened. So as the exploded view shows (see Figure 12) the number of axes to assemble the buttons, is one.

Motor sub-assembly

The motor sub-assembly allows three motion features:

1. Rotation of blade
2. Rotation of fan head
3. Tilting fan head

The rotational axis and electromagnetic coil drive the movement of the propeller blades, while the gearbox, rotation button, and pivot bracket enable oscillation of the fan head (see Figures 14, 15, 16 and 17).

Typically, a motor sub-assembly comprises numerous standard components, such as the gearbox and electromagnetic coil, around which custom parts must be designed. The neck connector acts not only as the interface between the custom-designed neck-tilting mechanism and the standardized elements of the motor sub-assembly, but also as the axis holder that enables the rotation of the fan head in relation to the stand. As illustrated in the exploded view, this sub-assembly features three distinct assembly directions, with the electromagnetic coil functioning as the foundational component (see Figure 14).

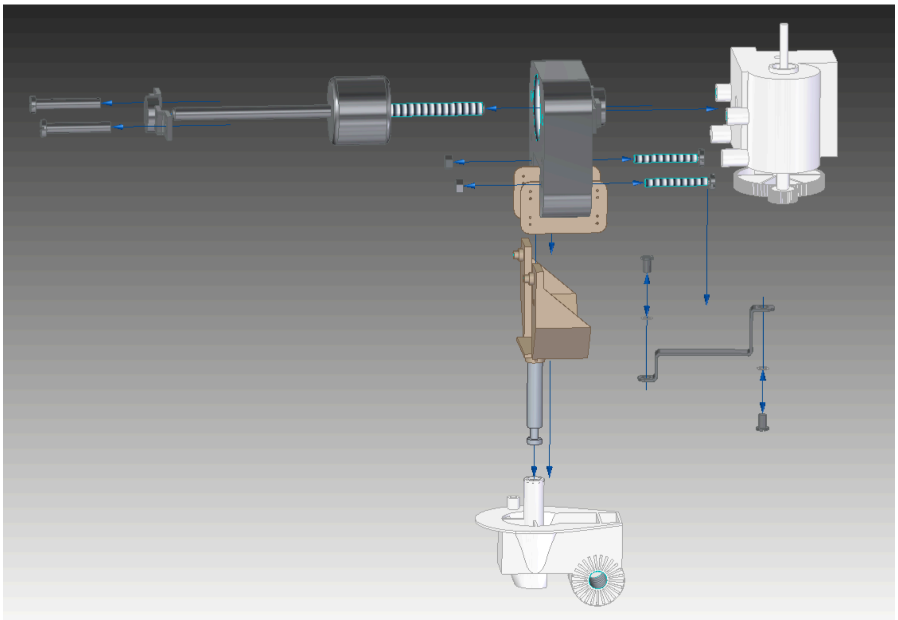


Figure 14 - Exploded view motor sub-assembly

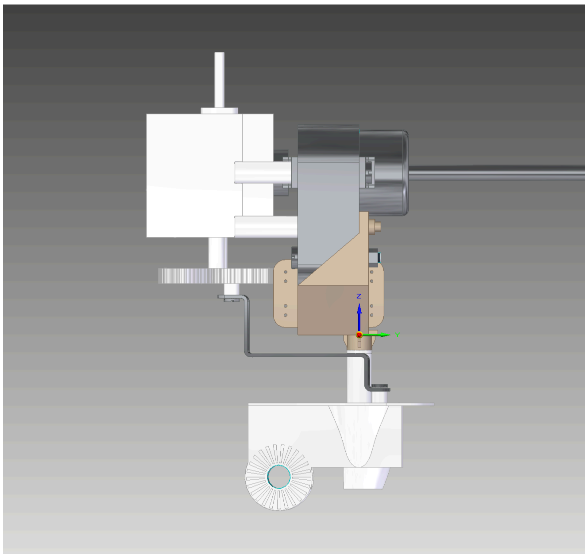


Figure 15 - side view motor sub-assembly

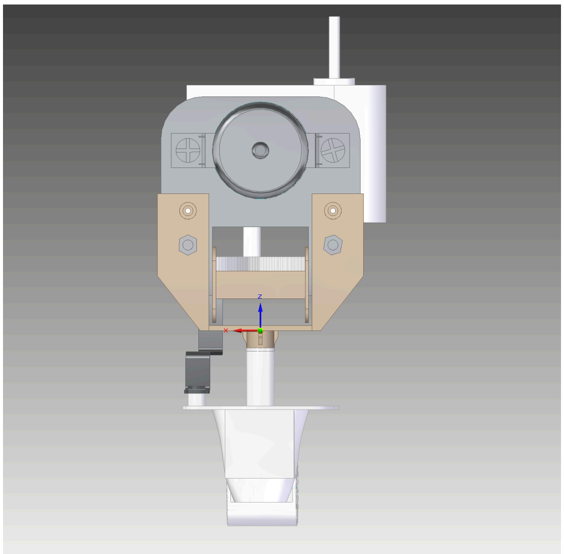


Figure 16 - front view motor sub-assembly

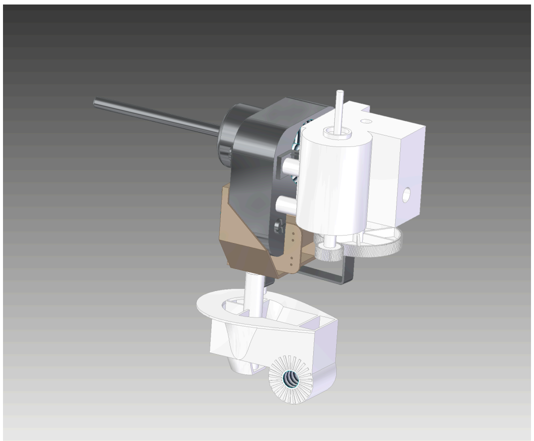


Figure 17 - ISO view motor sub-assembly

Fan head sub-assembly

The fan head sub-assemblies purpose is mainly for safe use and aesthetics, see Figure 18, 19, 20 and 21. The propeller is rotating with help of the motor sub-assembly, therefore the fan head has a front and back mesh guard whose function is to protect the user from the propeller. The motor cover front and back is instead protecting the user from the rotating gearbox and pivot bracket, as well as protecting the fan from both the user and environment with intention to make the fan last longer. It is essential that the fan head design also facilitates effective heat dissipation to minimize the risk of motor overheating.

The top-mounted button functions as the user interface for controlling the oscillation of the fan head: pulling it up engages the oscillation mechanism, while pushing it down disengages it. Additionally, it locks the internal rotation system, preventing the rotation button itself from turning and ensuring that only the fan head oscillates.

The assembly of the fan head sub-assembly is straight forward. However it still requires three assembly directions and there are two base parts from which all other parts are related, the motor cover front and back as seen in the exploded view (Figure 18).

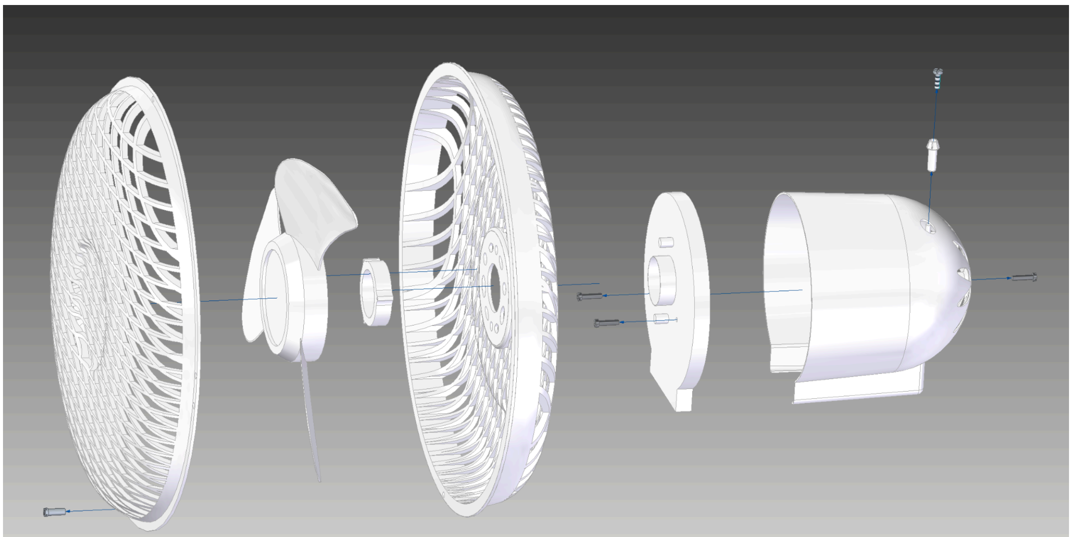


Figure 18 - Exploded view fan head sub-assembly

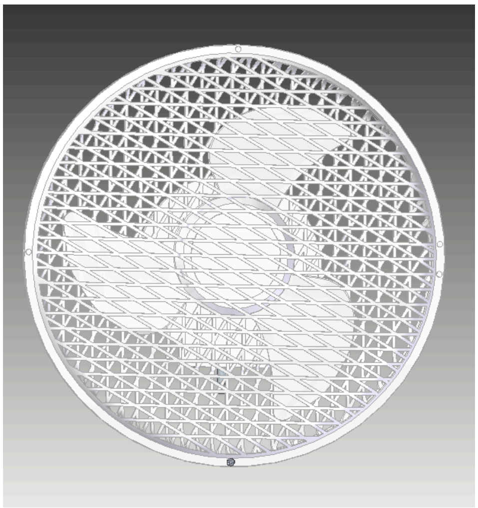


Figure 19 - Front view of fan head

Figure 20 - ISO view of fan head

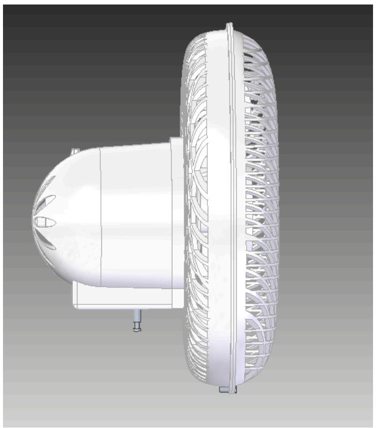


Figure 21 - Side view of fan head

Stand sub-assembly

The stand sub-assembly is giving support to the fan head and protects the button sub-assembly. This sub-assembly also promotes stability of the fan. It is therefore important that it is stable and doesn't slide easily on common surfaces like wood, metal or plastic.The number of axes needed for assembly is three.

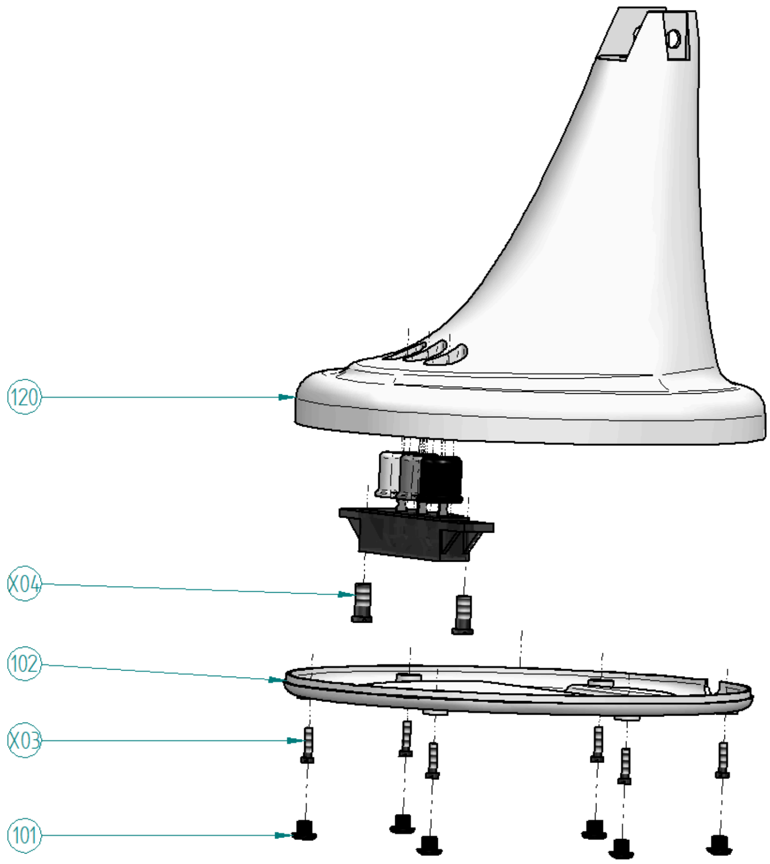


Figure 22 - Exploding view of stand sub-assembly

3. Function and assembly feature analysis/Assembly process and sequencing

3.1 List of operations

Step one towards defining the assembly process of the table fan is the creation of x operations, which is a comprehensive list of operations. This list was created complete with its own physical verification in the step by step assembly of the single product. As a first approach, designating overall sub-assembly classifications such as assembly operations, button unit, stand, motor assembly and final assembly was done on top of the box for insertion and handling tasks. Second, each assembly task was broken down into individual parts that were utilized in the task so as to eliminate any ambiguity that may stem from component mixing. Finally, every operation was assigned a definable precedence whereby a particular step can only follow after others have been completed. This enabled effective assembly of the table fan devoid of resultant error.

Table 3 - Operation list

Subassembly	*Sub-sub assembly*	*Op*	*Handling Operation*	*Parts*	*Precedence*	*Time (s)*
Stand Assembly	Button Body Bot tom	1	Attach lock button spring to button lock plate	Lock button spring Button lock plate	-	5,2
		2	Button lock plate inserted into button body bottom	Button lock plate Button body bottom	1	10,8
		3	Button unlock plate attached to to button lock plate	Button unlock plate Button lock plate	2	5,8
		4	Insert Speed 1 or 2 plate into button body bottom	Speed 1 or 2 plate Button body bottom	3	7,8
		5	Spring metal plate inserts into button body bottom	Spring metal plate Button body bottom	4	14,6
		6	Lastly wire bracket gets put into button body bottom	Wire bracket Button body bottom	5	18,2
	Button body top	7	Button metal goes into button body top	Button metal Button body top	-	11

Subassembly	*Sub-sub assembly*	*Op*	*Handling Operation*	*Parts*	*Precedence*	*Time (s)*
		8	Button spring attaches to button metal	Button spring Button metal	7	53,6
		9	White push pin also attaches to button metal	White push pin Button Metal	8	14,2
	Button Assembly	10	Button body bottom and button body top gets fixed together	button body bottom Button body top	6, 9	19,8
		11	White, grey and black button gets all inserted onto the button assembly	White button Grey button Black button	10	12
	Stand body	12	Power cable get arranged in the stand body	Power cable Stand body	11	11,4
		13	Power cable bracket gets attached by M7x12 screw onto the stand body	Power cable bracket M7x12 screw Stand body	12	31,4
		14	Plastic wire box gets attached with M6x8 screw onto the stand body	Plastic wire box M6x8 screw Stand body	12	22
		15	Button assembly gets inserted into the stand body with M7x12 screw	Button assembly M7x12 screw Stand body	12	26,2
		16	Bottom plate attaches to the stand body with M6x12 screw	Bottom plate Stand body M6x12 screw	13, 14, 15	73,2
		17	Feet gets attached onto the stand	Feet Stand	16	11,6
Head Assembly	Motor	18	Plastic spacer attaches to Neck	Plastic spacer Neck connector	-	5

Subassembly	Sub-sub assembly	Op	Handling Operation	Parts	Precedence	Time (s)
			connector			
		19	Neck connector screws onto El. mag. coil with M6x27 and Nut 7mm	Neck connector El. Mag. coil M6x27 screw Nut 7mm	18	46,6
		20	Gearbox, shaft bracket and El. rotor gets screwed together with the Neck connector and El. mag. coil with M6x35 screw	Gearbox Shaft bracket El. rotor Neck connector El. mag. coil M6x35 screw	19	50,8
	Motor assembly	21	Pivot bracket gets attached to neck tilter with M10x12 screw and black spacer	Pivot bracket M10x12 screw Black spacer Neck tilter	-	16
		22	Neck tilter and Motor gets attached together with M6x12, M10x12 screw and black spacer	Neck tilter Motor M6x12 screw M10x12 screw Black spacer	20,21	35,6
		23	Motor cover back gets attached to the motor with M7x13 screw	Motor cover back Motor M7x13 screw	22	27,4
		24	Motor cover front gets attached to the motor with M7x21 screw	Motor cover front Motor M7x21 screw	23	39,8
		25	Rotation button gets attached to the motor with M6x12 screw	Rotation button Motor M6x12 screw	24	15
	Motor+fan assembly	26	Mesh guard back gets attached with a plastic nut 40mm to the motor assembly	Mesh guard back Plastic nut 40mm Motor assembly	25	12,8
		27	Propeller gets attached on top of that	Propeller	26	4,2
		28	Plastic cover gets screwed onto the mesh guard front with M8x8 and spacer	Plastic cover Mesh guard front M8x8 Spacer 12mm	-	61,4

Subassembly	*Sub-sub assembly*	*Op*	*Handling Operation*	*Parts*	*Precedence*	*Time (s)*
			12mm			
		29	Mesh guard front gets attached onto the moto+fan assembly with M4x11 screw and 5mm nut	Mesh guard front Motor+fan assembly M4x11 screw Nut 5mm	27,28	55,4
Final assembly		30	Head and Stand assemblies gets attached together with M9x33 screw and a Nut 10mm	Head assembly Stand assembly M9x33 screw Nut 10mm	17,29	38,4

The average total assembly, including both insertion and handling, was 757.2 s. That results in a total time of over 12 minutes to assemble the entire table fan.

3.2 Liaison diagram

The liaison diagram, shown in Figure 23, captures the relationships and interaction points linked with the elements of the fan assembly. This diagram provides the initial steps for working on the assembly design as well as operation sequences along with precedence diagrams. The diagram captures both mechanical fastenings like screws and physical interfaces such as bolts, springs, and inserts, thus displaying the ways in which the parts are interrelated.

This dual-layered approach, distinguishing between screw-based connections and direct physical contacts, enhances clarity while simultaneously permitting better judgement when planning the assembly and optimizing the processes.

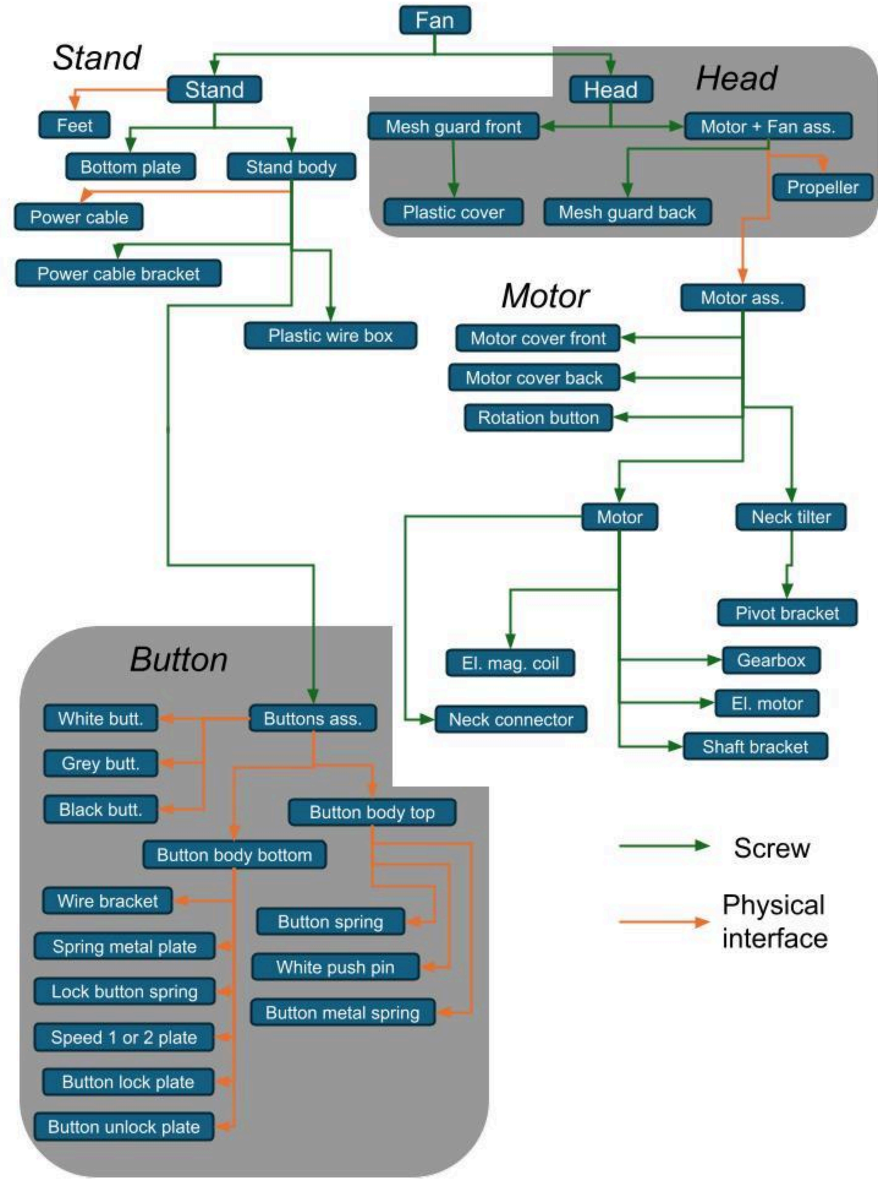


Figure 23 - Liaisons Diagram

3.3 Precedence diagram

As follows, we make the precedence diagram using the operations for assembling the table fan from the list made in the previous steps. This diagram illustrates, in a graphic form, the proper order that operations should follow, depicting which activities must be done first before others can commence, see Figure 24. It depicts the relationships form some of the tasks in the different subassemblies such as the button unit, the stand, and the motor parts, and the relationships of dependencies within the task order. These understandings of precedences are critical to create an efficient assembly process and serves as the basis for assigning work elements to specific workstations. Additionally, this smoothes the process for line balancing.

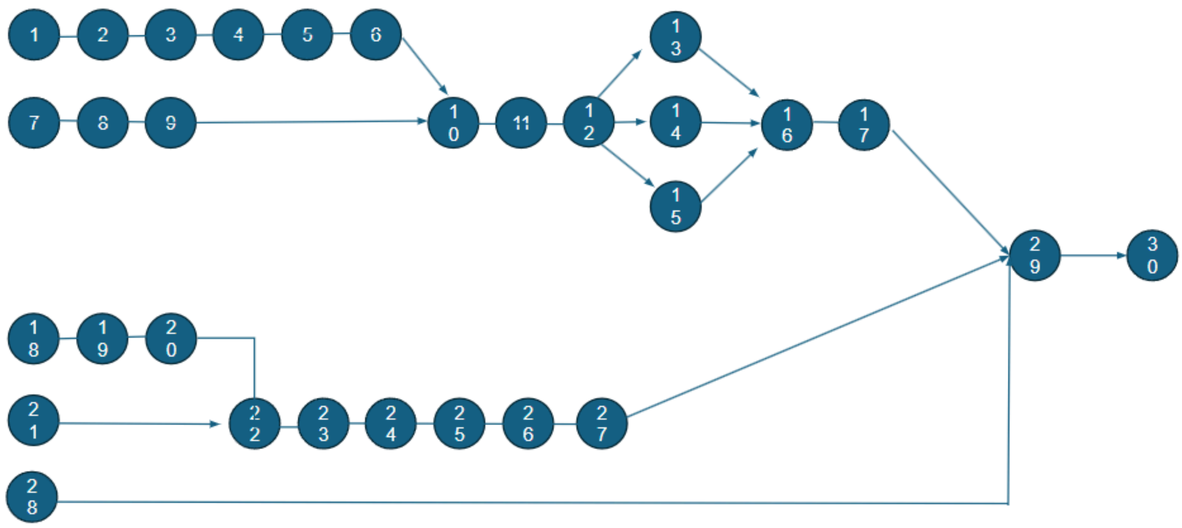


Figure 24 - Precedence diagram

3.4 Liaison sequence diagram

The table fan is made from many parts and subassemblies. Each may be assembled in different orders depending on the design constraints and accessibility. In order to assess and depict feasible assembly pathways, a Liaison Sequence Diagram (LSD) was created as illustrated below in Figure 25. The purpose of this diagram is to show the structural order of the linkages of the parts to achieve assembly which considers physical liaisons. Because of the numerous possibilities, only a subset of all sequences is shown. Furthermore, the diagram fix some boundaries for her flexible subassemblies like motor housing with blade set and cap while letting other boundaries free on purpose to illustrate the LSD use. The shaded boxes mark liaisons that are already completed. The lines show the most optimal sequence evaluated for assembly flow.

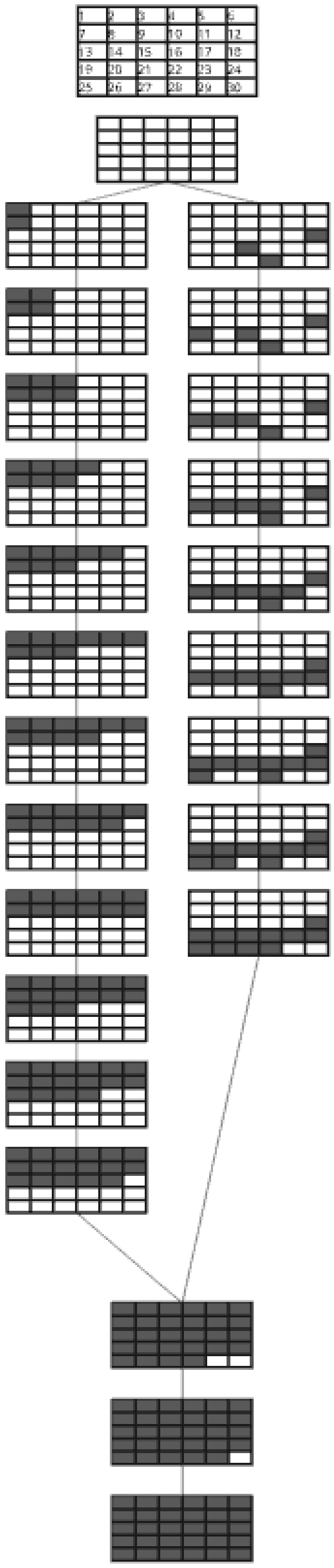


Figure 25 - Liaisons Sequence Diagram

3.5 Critical-assembly functions

Button sub-assembly - The button sub-assembly (see Figure 26) is regarded as highly assembly-critical owing to its functional significance and the type of components comprising it. As individual parts, it might not be out of bounds in terms of size, weight, or alignment angle among other components; however, from a tactile feedback, precision motion, and reliable actuation perspective, they are extremely sensitive to misalignment and manual error of even the smallest degree. Almost all assembly processes include small parts that interact on a high precision level and are often dynamic like springs or caps. From the sub-assembly perspective, any error during assembly will have an impact on the responsiveness or mechanical integrity of the button. This in turn may influence the user's interaction with the system or how the system operates later on. Therefore, complete attention must be directed while consistently locking, leveling, and securing aspects of the button to achieve optimal performance and enhanced lifespan.

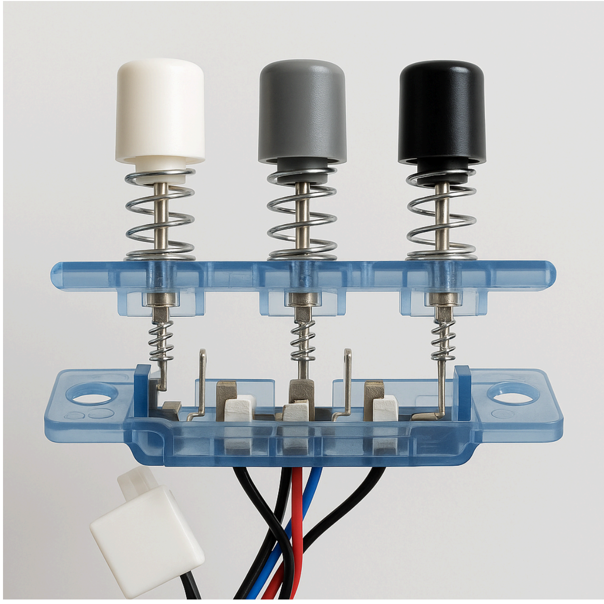


Figure 26 - Button assembly

Fasteners and Joints - Parts within an assembly are held together using fasteners and joints that are important to the mechanical integrity and stability of the assembly, therefore fasteners and joints are considered assembly-critical components. They serve the primary purpose of holding components together while withstanding mechanical loads during use. Failure to properly install a fastener, for example, may include wrong torque, wrong orientation, or even miss a step, which could progressively lead to the fastening loosening and misalignment over time, resulting in structural failure. With regards to this assembly, screws like X01 (M9x33) and X03 (M6x12) and nuts X02 (10mm) are vital in fastening other major sub-assemblies like the stand and buttons. When working on alignment-critical engagements or when interfacing with load-bearing structural components, careful attention is paramount. Consequently, these parts require precision during the fastening process which entails appropriate tools and steps to check accuracy to maintain the desired quality and functional Kawofection consistency that is expected.

4. Assembly Scenarios

To find the best production scenario, several considerations need to be made. The most important decision criteria for this are the times, costs, and benefits involved with each scenario. Therefore, a thorough understanding and comparison of the different criteria in each case is needed. There are some indicative approaches to provide a direction of when to use which assembly mode. One example of such an approach is the graph seen in *Figure 27*, which gives an indication of when to use manual assembly, an one-robot station, a multi-station line with robot(s), or a high speed automation line based on number of components in the product, batch size, and yearly volume (Monetti and Maffei, 2025).

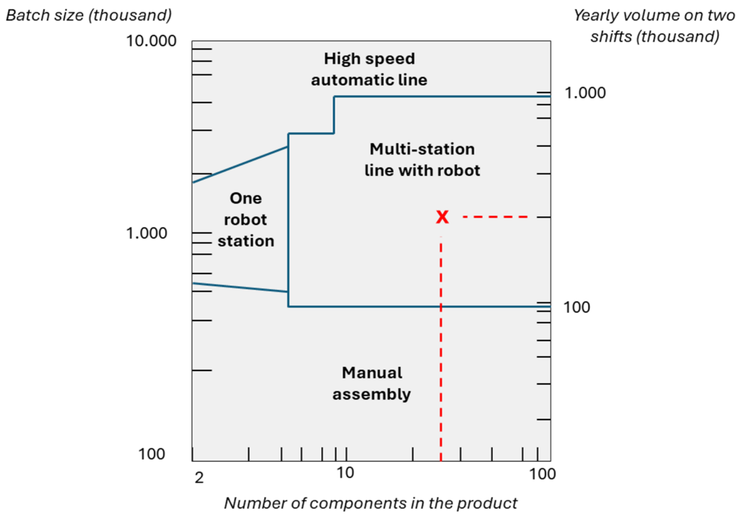


Figure 27 - Choosing an Assembly Mode

4.1 Production Parameters

Before designing the assembly scenarios, we had to calculate the Takt time which needs to be fulfilled to meet the production goals of estimated annual demand within the total available time. To calculate the Takt, a few justified assumptions had to be made regarding the frame conditions.

First, the total available time was calculated by looking at factors such as available working days, which we decided to be 251 and the amount of working hours per day, which we decided to be 8 hours, corresponding to one daily shift. Multiplying these two numbers resulted in a total available time of 7 228 800 seconds per year.

Next, the annual demand was calculated based on the following four steps:

1. Retrieving the estimated annual sales for table fans worldwide, which gave a revenue market share of 15 049 286 400 SEK.
2. Reducing this number to the market share for table fans only sold in Europe, which has been considered at 20% of worldwide sales, resulting in 3 009 857 280 SEK.

3. Estimating our company's distinct market share at 0,35% of the European market based on limited regional sales area and competition which leaves us with a revenue market share of 10534500,48 SEK per year.
4. Dividing the market share by the fan price excl. VAT, which is 119,20 SEK.

These steps resulted in an annual demand of 88377 table fans.

Given the calculated frame conditions, the nominal Takt time could then be calculated step-wise according to the following formulas:

$$Required\ Production\ Rate\ R_p = \frac{Annual\ Demand\ [units/year]}{Total\ Available\ Time\ [s/year]} = \frac{88377\ [units/year]}{7228800\ [s/year]} = 0,01223 [units/s]$$

=> $Takt\ Time = 81,795\ [s/unit]$

However, to account for inefficiencies and disruptions in the production line, we applied a safety margin by considering the following efficiency factors for the line efficiency η_L:

Table 4 - Efficiency Factors for line efficiency

Equipment failure	98%
Power outage	98,5%
Material shortage	98%
Quality issues	96%
Labour related delays	98%
Total	**89%**

Given this line efficiency, we calculated the adjusted Takt time as:

$$Adjusted\ Takt\ Time = \eta_L * Takt\ Time = 0,89 * 81,795\ [s/unit] = 72,797\ [s/unit]$$

Finally, to make our balancing more realistic, we also wanted to account for repositioning time though, which we did by reducing the adjusted Takt Time to the effective Takt Time. The repositioning time per worker T_r has been estimated to be around 8% of the Takt time, which resulted in 5,82 seconds and is coherent with standard assumptions of T_r being within a range of roughly 4 to 10 seconds for most tasks in production. Deducting this number from our adjusted Takt Time leaves us with an effective Takt Time and effective Cycle Time T_{max} per workstation of 66,978 seconds, meaning that all work contents at each single station will have to be completed within that time.

Now that we have our key production metrics, the different scenarios can be designed and evaluated. Based on *Figure 27* and given our high number of components as well as the yearly production volume of around 90000 products in one shift, the preferred assembly mode for our table fan would be manual assembly. However, we will also evaluate a partially automated scenario with multiple stations and robots since our annual demand is close to 100.000 units and employing a two shift model, our production would yield around 180.000 units per year which would point us towards using that mode. This consideration will allow us to account for future increases in demand. In the following, both scenarios will be evaluated.

4.2 Manual Assembly

In this chapter a manual assembly scenario will be defined by applying different line balancing methods to find the best possible result in terms of line performance. The underlying assumption is that operations can be split up into different steps and distributed across multiple workstations.

The assembly sequence is restricted by the dependency of each operation, which can be seen in the precedence diagram. But some operations are independent or can be done at multiple stages of the assembly process. This enables the freedom to optimize the sequence by balancing the stations based on their cycle time in relation to the required Takt time which has been previously defined.

To balance the sequence we evaluated the results of three common methods, the largest candidate rule (LCR), the ranked positional weight (RPW) algorithm, and the Kilbridge & Wester (K&W) algorithm, as well as creating a custom method to account for the independence of the top and bottom subassemblies and also making it possible to have parallel lines, thus lowering the throughput time.

To choose the most suitable method, we considered the following criteria:

- The number of unique stations to reduce variability and ease standardization.
- The number of workstations overall to minimize space and labor needs.
- Throughput time to lower WIP, shorten lead times, and improve responsiveness.
- Total idle time that occurs when pacing the line by the longest operation (synchronous transport) to lower non-value adding time.
- Efficiency which provides info on the overall line performance.

As seen in Table 5, the sequence created by our custom method fulfills these requirements best overall.

Table 5: Comparison of balancing methods

Criteria	*LCR*	*RPW*	*K&W*	*Custom*
Unique stations (#)	12	13	12	7
Workstations (#)	13	14	13	13
Throughput time (s)	802	858	785	268
Idle time (s)	106	143,2	89,2	70,5
Station efficiency (%)	86,5	82	86,5	85

Even though the theoretical number of workstations T_{wc} has been calculated as 10, the minimum number of workstations we could achieve here is 13 due to the fact that the operations each have set times and some dependencies, hence not every workstation can be perfectly utilized and additionally the T_{wc} does not consider the repositioning time either.

One point which could improve the station efficiency of our custom method even more is to directly add packaging in the last station since it is the least utilized (currently around 57%). However, the feasibility of this would highly depend on the packaging time and other requirements such as feeding of packaging material to the station, potential required additional equipment, needs for quality checks before packaging, and more.

To see how packaging would affect the last operation, a simple test was constructed outside of the main assembly operations. This included: grabbing the assembled fan, lifting it, putting it in a box, adding a manual, taping the box shut and putting a sticker on it. When performing these steps, the average time was 22 seconds. To give some extra safety, a time of 28 seconds was assumed for packaging of the fan. This is also supported by Maula et al. who have performed a similar study with a much larger tower fan which has had some extra steps in packaging such as bagging, adding a remote, and more. On pages 103-105 they describe their packaging process based on a MTM analysis. Adding up their estimated times only for the operations which we thought relevant (50% of OP1 since our boxes will be already made, as well as operations 3, 12, 15, and 19-22), we get 800 TMUs. Since 1 TMU = 0.036 seconds, that results in a time of 28,8 seconds which is very close to our measured time with margin. When adding this operation to the last station G, the total average station efficiency of the line increased to 91% resulting in a well-balanced assembly line.

A visualization of the sequence, the appointed operations (OP), number of workstations per station (WS), and the cycle time pace of the synchronous flow (CT Pace) can be seen in Figure 28. The pace is chosen based on the station with the highest cycle time, read more under 5.1 Line Layout. With a pace of 67s, including safety margins, the line has an annual production volume of 107892 units in comparison to the estimated demand of 88377.

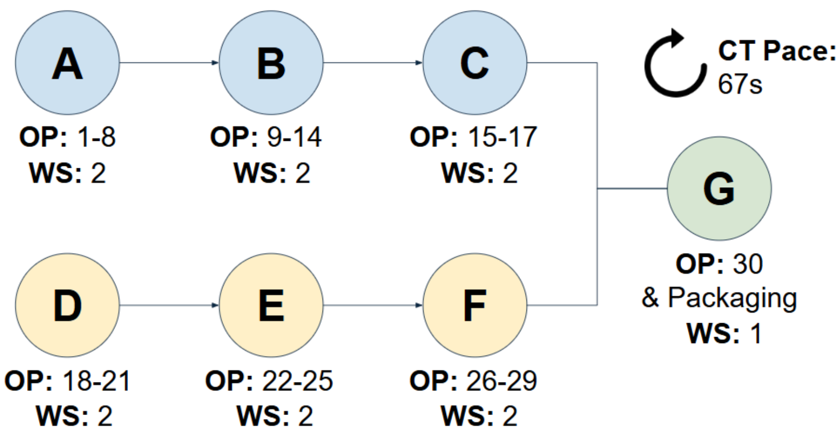


Figure 28 - Operation sequence

4.3 Partially Automated Assembly

In this chapter a partially automated assembly scenario will be defined. We know that our product has some intricate and flexible parts. Therefore, the first step is to determine which parts can be generally handled by robots and automated machines and which ones would be very difficult to handle automatically and better be handled manually. This is to rule out the least suitable parts for automatic handling from the start which falls under the case of inherently manual operations in partial automation.

Based on the DFA-A analysis performed in chapter 6.2 Design for Automated Assembly, the suitability for automation has been determined for each part as well as on a product level following the Eskilander method, as can be seen in Appendices F and D. A summary of the results can be found in Table 6 below:

Table 6: Summary of DFA-A Results Per Sub-Assembly

	Motor	*Head*	*Buttons*	*Stand*
Min. Part-level score	64	62	50	68
Max. Part-level score	98	78	114	122
Average of Part-level scores	78	74	83	89
Product-level score	19	27	31	35

The analysis implies that on a part-level the stand shows the best suitability for automation with an average score of 89. The button has the second highest average score of 83, however looking at the individual scores one can see that the lowest score for a part is 50 while the highest is 114 which means that there are some outliers. There are two parts, the springs, which are especially unsuitable for automation. Both the motor and the head do not promise good results for automatability on a part level either. The perfect score for suitability on a part-level is 162. Hence, the stand could potentially be automated but the other sub-assemblies are more critical.

On a product level, the Motor sub-assembly has by far the worst score with 19. The head is a bit better with a score of 27 but still not good. With a maximum possible score of 63 on the product-level, one could argue that the scores of 31 for the buttons and 35 for the stand could be acceptable for automation though.

Based on these insights and the existing precedence constraints, it can be derived that operations 3-7 and 9-17 can be automated, as they do not involve the springs. However, based on our practical experience with assembling and disassembling, we do not think that operations 3, 5, and 14 can be automated either due to being fiddly or intricate which leaves us with operations 4, 6, 7, 9-13, and 15-17 which could be automated. Due to precedence constraints it would not be possible to change the order of operations and since operations 4, 6, and 7 are in between several non-automatable tasks and do not take long, it does not make sense to automate them and then switch back to manual several times in between. A similar reasoning is the case for operation 9 since it is the only missing part of the button body top subassembly which would then require an additional fixture just for this operation which is not feasible. Operation 12 is also a bit hard to automate because it involves pushing a cable which is a flexible part into a half hole. There would need to be several re-orientations and fixtures for different subcomponents between operations. Given the frequent switches between need for manual assembly and re-orientations and opportunities for automation, we will consider human-robot collaboration for operations 1-17. According to Tran, cobots are performing well with screwing and pressing operations which is needed for some of our operations. [19]

Looking at the suggested sequence for the manual scenario outlined in Figure 28, one can see that a similar flow might be feasible in this case. Since the lower one of the parallel lines which consists of operations 18-29 is assembling the head and motor, it can stay a manually assembled parallel line with cycle time of 66,978 seconds. This means that the balancing for the lower stream can be considered to stay the same as well. Given that the cycle time for partially automated systems is normally decided by the slowest station, we will assume that the cycle time for the automated stations should be the same as for the manual ones. This will allow us to minimize the need for storage buffers, which would now only be needed for safety to avoid a full production stop in case the automated stations break down. For the upper stream, a slightly different workstation distribution needs to be designed, however as operations 1-17 will be partly automated. The most important parameters to consider in designing the station are feeding and orientation of parts. Accuracy and sensor feedback are critical parameters in assembly operations which is why we introduced some vision control as well.

Table 7 - Operation Times

Operation	*Mode*	*Collaboration Description*	*Estimated Time [s]*
1	Manual	Manual assembly supported by Vision	5.2
2	Manual	Manual assembly supported by Vision	10.8
3	Manual	Manual assembly supported by Vision	5.8
4	Cobot	Simple pick-and-place by cobot + slight human alignment	4
5	Manual	Manual assembly supported by Vision	14.6
6	Cobot	Human may hold while cobot	10

		screws bracket.	
7	Cobot	Simple pick-and-place by cobot	3
8	Manual	Manual assembly supported by Vision	53.6
9	Cobot	Pick-and-place by cobot of small part with vision + slight human assist	8
10	Cobot	Human places bottom part, Cobot picks and presses the top part on the bottom	10
11	Cobot	Cobot inserts buttons with pick-and-place and push	9
12	Cobot	Manual routing aided by cobot holding/positioning	8
13	Cobot	Human may hold while cobot screws bracket	15
14	Cobot	Human will place and attach the cables in the box and cobot will screw it	15
15	Cobot	Gripper cobot picks and places stand body into fixture (reversed). It picks and places the button assembly into stand body. Screwing cobot screws.	10
16	Cobot	Human places bottom plate onto stand. Robot screws 6 screws.	12
17	Cobot	Feet are inserted by Fixtured insertion system	6

The flexible manufacturing system will result in shorter lead times and lower operator load. We have also considered fully automating a few operations, however that was not feasible at all. Hence, the suggested sequence is as follows:

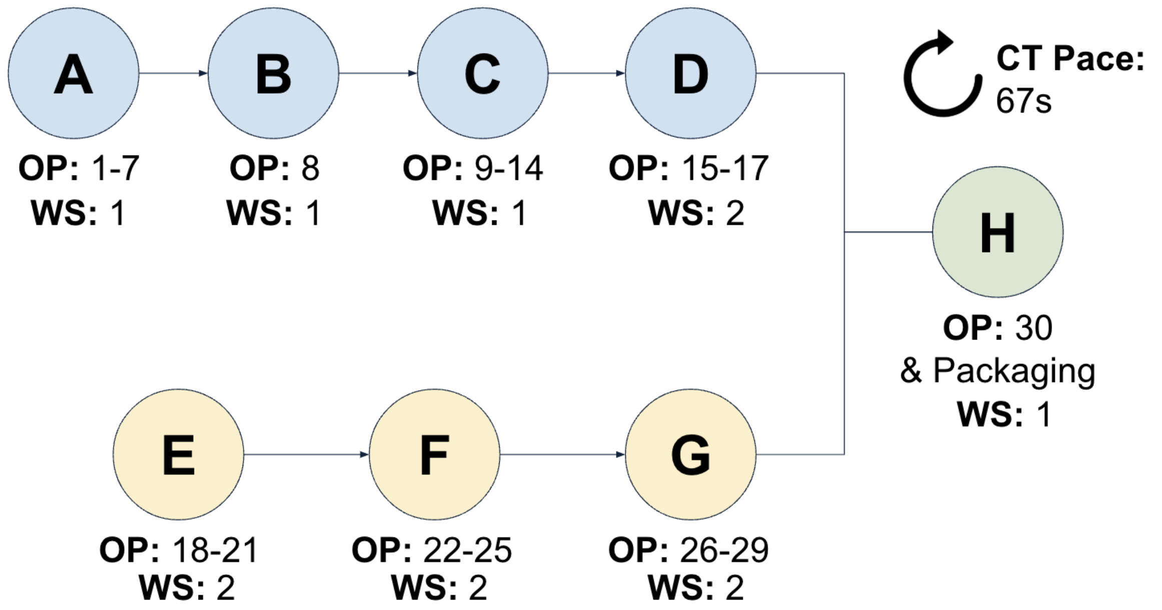


Figure 29: Operation Sequence Automated

Since DFA is an iterative approach in practice it would make sense to re-evaluate the scenario based on the design improvements suggested in 6.2.1 Design improvements for automated assembly which could potentially allow for a fully automated system. As could be seen from the previous analysis, there is a big opportunity for enhanced automation potential after some design improvements. In the current scenario, the balancing is not very good given the many constraints regarding automation.

5. Layout

Based on the previous evaluations of both the manual and partially automated assembly scenarios, the following section will explore their specific layout designs. It will cover both the general layout, as well as more detailed aspects at the station level. These include descriptions of fixture and tooling requirements, specifications of the workplace itself in terms of operator ergonomics, as well as feeding, handling, and gripping tasks.

5.1 Manual Line Layout

Some points which suggest that the manual scenario is more suitable than an automated scenario are that the current design has a lot of small, fiddly and intertwined parts in tight spaces, which is hard for robots to reach and work with. The current design also has multiple operations that require using two hands. Manual assembly also enables more flexibility in our stations by not limiting what operations we do where too much and it involves lower initial capital investment regarding assembly robots, sensors and feeding systems, as it depends more on workers which incur higher variable instead of fixed costs. Furthermore, manual assembly is suitable for producing single products or at least a limited range of products, which is the case for our table fan production as we only have one model as for now.

The manual assembly will use a line layout to account for the two parallel operation sequences merging at the last station. The workstations will be using a bench assembly where operators will perform a certain station's operations at a fixed location. This enables efficient and ergonomic work as well as easier standardization which is supported by the relatively fixed product design.

To support the workstations, a mechanised conveyor belt will be used to transport the subassemblies on trays between each station, as seen in *Figure 30*. The transport system will move synchronously to avoid buffers and unwanted WIP which ties up capital in the assembly line, making it less flexible to changes in demand. To avoid waiting times, it will use a pacing with margin approach to keep up with the takt time whilst still allowing margin of errors to finish the parts and minimizing scrap and encouraging a good working environment for the operators.

Besides the motorized transport system, the system will also use a manual feeding system to benefit from human interaction from the operators when verifying availability, as well as sorting, orienting and locking into the assembly fixture. The material will arrive at each workstation in kits that include everything needed to complete one fan. Kit feeding will be manually carried out by an operator using a production cart or similar which moves on the inside of the assembly line, as seen with the dotted red line in *Figure 30*.

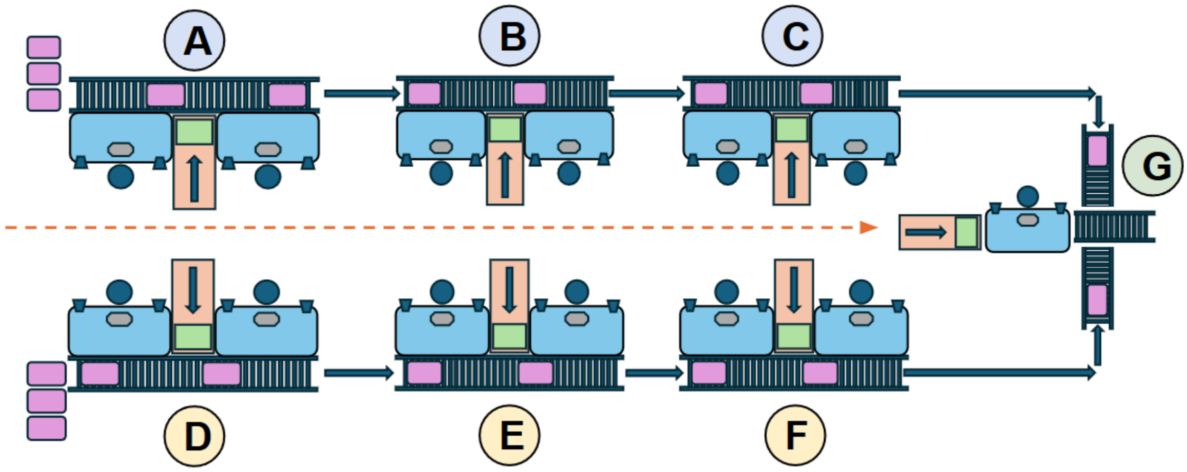


Figure 30 - Line layout and material flow

The layout with parallel lines has some advantages in terms of worker ergonomics and productivity, similar to a U-shaped layout. Given the opportunity to rotate workers, it introduces human variability and thereby reduces emotional stress and physical strain.

5.1.2 Station Level Layout

The assembly line will have seven unique stations (A-G) that are standardized to perform the appointed operations. Within each station there can be multiple parallel workstations, but maximum two in the chosen layout. In total there are 13 workstations each with one operator assembling simultaneously as the others. See *Figure 30* for a 2D visualization of a typical station.

For incoming kit parts and required tools and fixture for each stations, see *Table 8*. Fixtures are used to stabilize a base object in place and enable the operators to use both hands when assembling, which results in more efficient and comfortable work.These are custom made vise fixtures that fit the geometry of the listed base objects, and to fasten it with enough force to keep it secure without damaging the part surface or structural integrity. For example, the spring-loaded vise fixture in Figure 31 shows how it can be angled to fit the operator's height and preferences for better ergonomics and easier access. This example with a flat surface would be suitable for the button body top and bottom assemblies.

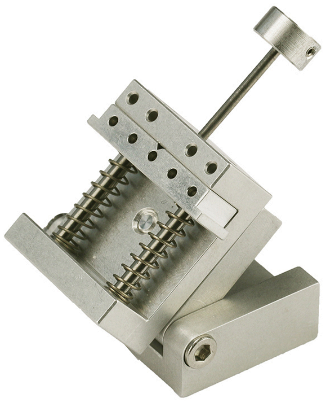


Figure 31 - Spring-loaded vise fixture example

Both the screwdrivers and the nut drivers are motorized and attached with a flexible and retractable wire to the workstation for easy accessibility and release. Nut drivers are used instead of socket wrenches because they handle small fasteners that require less torque and allow access to tighter spaces with a smaller turning radius. Metal tweezers are only needed on the first station to handle smaller and very thin parts in a fast and accurate way. For the last station, a handheld tape dispenser is used for packaging to shut the boxes closed.

Table 8 - Station overview

Station	*Op.*	*# of WS*	*Kit parts*	*Equipment*
A	1-8	2	Lock button spring, Button lock plate, Button body bottom, Button unlock plate, Speed 1 or 2 plate, Spring metal plate, Wire bracket, Button body top, Button metal, Button spring	Fixtures: - Button body bottom - Button body top Tools: - Metal tweezers
B	9-14	2	White push pin, White button, Grey button, Black button, Power cable, Stand body, Power cable bracket,	Fixtures: - Button body assembly - Standy body

			M7x12 screw, Plastic wire box, M6x8 screw	Tools: - M7 screwdriver - M6 screwdriver
C	15-17	2	Button assembly, Bottom plate, M6x12 screw, Feet, Stand	Fixtures: - Stand body Tools: - M6 screwdriver
D	18-21	2	Plastic spacer, Neck connector, El. mag. coil, M6x27 screw, Nut 7mm, Gearbox, Shaft bracket, El. rotor, M6x35 screw, Pivot bracket, M10x12 screw, Black spacer, Neck tilter	Fixtures: - El. mag. coil - Gear box Tools: - 7mm Nut Driver - M6 screwdriver - M10 screwdriver
E	22-25	2	Motor, Motor cover back, M7x13 screw, Motor cover front, M7x21 screw, Rotation button	Fixtures - Motor assembly Tools - M7 screwdriver
F	26-29	2	Mesh guard back, Plastic nut 40mm, Propeller, Plastic cover, Mesh guard front, M8x8 screw, Spacer 12mm, Motor+fan assembly, M4x11 screw, Nut 5mm	Fixture: - Mesh guard back - Motor assembly Tools: - M8 screwdriver - M4 screwdriver - 5mm Nut driver
G	30 & packaging	1	Head assembly, Stand assembly, M9x33 screw, Nut 10mm, Packaging box, User manual, Information sticker	Fixture: - Head and stand assembly Tools: - 5mm nut driver - Handheld tape dispenser

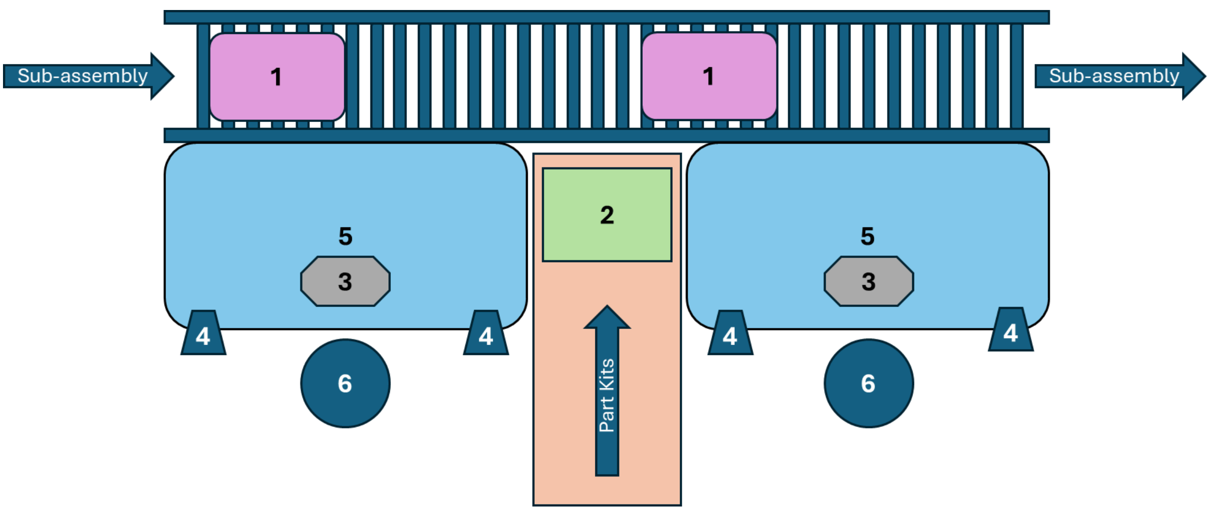


Figure 32 - 2D view of example workstation.

Depicted in Figure 32: (1) are the trays which the subassemblies are transported on, (2) are the kits, (3) are the fixtures, (4) are the power tools, (5) are the tables, and (6) are the operators.

5.2 Automated Line Layout

The layout for the automated assembly scenario will look somewhat similar to the manual flow since the automation potential was limited. We will need 3 fixtured screwdriver cobots for the 3 stations, A, C, and D which includes feeding such as the one offered by Weber. Further, a fixtured insertion system including automated feeding is needed to attach the feet in operation 17 [16]. Some of the parts can be fed by tube feeding which is also offered by Weber and is customized to the parts geometry to avoid jams. The screws could be fed through bowl feeders and dedicated feed tracks. However, considering this is not a fully automated environment, the same feeding mode as in the manual setup can be used as well. Given that we cannot really calculate the feeding and insertion costs for automated setups. There will be a buffer after operation 14 to allow decoupling between stations which will help to absorb timing mismatches or downtime upstream or downstream and smoothen the flow. [18]

The layout will look as can be seen in Figure 33:

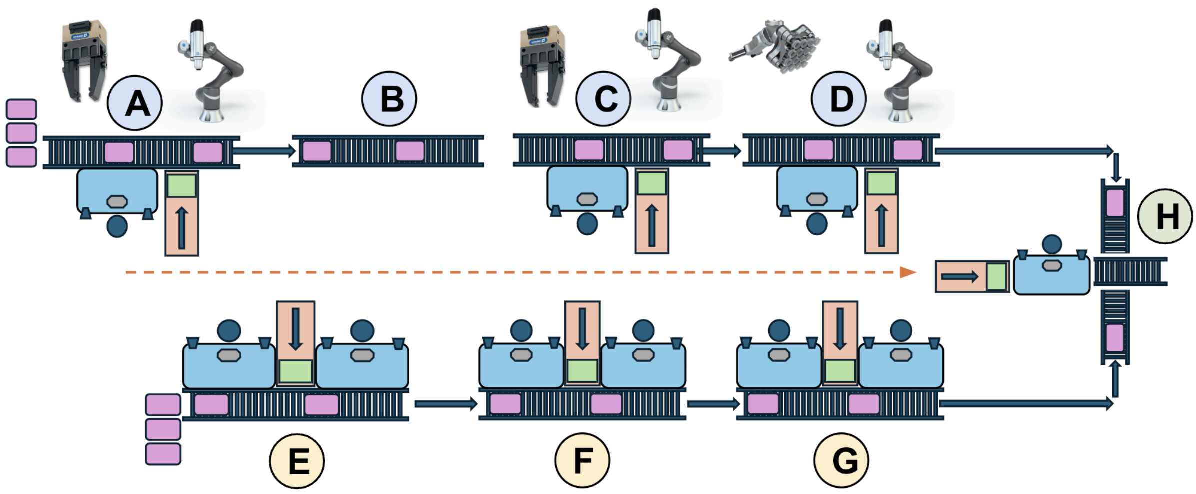


Figure 33: Layout Design for Partially Automated Assembly Scenario

6. Design for Assembly

The current fan design has been analyzed in detail in the previous sections with respect to its suitability for both assembly and manufacturing. This section explores the potential improvements in each sub-assembly, considering both manual and automated assembly methods and compares it to how efficient the current design is for easy assembly.

6.1 Design for Manual Assembly

A detailed analysis of all existing parts and their functions was conducted to calculate the DFMA (Design for Manual Assembly) efficiency index, e_{ma}. The most common method to evaluate the DFA efficiency index is Boothroyd-Dewhurst's method (BDM). The main focus of this method is the insertion and handling time of each assembly operation. By minimizing the assembly time, the efficiency will increase. This method is especially suitable for evaluating existing parametric products.

The BDM is a two-step method, where the first step is to classify what parts are essential and not, and thereafter make an analysis of handling and insertion time of each part [10].

To determine whether a part is essential, three key questions are typically asked:

1. Must the part be of a different material?
2. Does the part move relative to all other items?
3. Is the part separated to allow assembly?

If the answer to any of the questions is yes the part is considered essential. Using this method nine parts could be removed, and $N_{min} = 47\, parts$. Parts such as the power cable bracket and its related screws could be removed. The power cable bracket does not move relative to other items and is not separate to allow assembly. Removing it would not affect the end user's experience. To get a better perspective of why that part was added in the first place a lot of research has been made to strengthen the decision to fully remove that part. As it holds the cables in the right place it could facilitate for the operator during the stand-assembly, however….

Additionally the plastic cover in the center of the front mesh cover and its belonging screws and spacers turned out to be non-essential (see Appendix G).

After N_{min} was determined the handling and insertion of the essential parts was analysed using reference tables of estimated handling and insertion time. The values of the total manual handling time ($t_{ma-handling}$), and the total manual insertion time ($t_{ma-insertion}$) was found, see table 10. The last parameter to determine the DFA efficiency index is the basic assembly time for one part, t_a. This parameter is an average time for handling and insertion and has a standard value of 3 s. Thereafter the DFA efficiency index could be calculated through the formula below:

$$e_{ma} = \frac{N_{min} * t_a}{t_{ma-total}}$$

Table 9 - Current design assembly time and efficiency

N_{min}	$47\ parts$
$t_{ma-handling}$	$123.88\ s$
$t_{ma-insertion}$	$197.5\ s$
$t_{ma-total}$	$321.38s$
t_a	$3\ s$
e_{ma}	43.87%

In comparison the calculated assembly time $t_{ma-total} = 321.38s$ is a lot lower than the average measured assembly time, 757.2 s calculated in section 3.1.

The DFA efficiency index is 43.87% for the manual assembly. To increase the efficiency changes of individual parts and features can be suggested and analysed to optimize the assembly.

6.1.1 Design improvements for manual assembly

An analysis of the design of each part with regards to manual assembly was made to see if there is potential of improving the DFA efficiency index. When conducting the BDM each part was evaluated as either hard or easy to align and position to find a reference insertion time. The design improvements for manual assembly in this report have been limited to identifying and proposing changes to the parts that were considered hard to align and position.

As seen in the BDM table all the nuts are considered hard to align and position. When it comes to assembling the fan sub-assembly, the mesh guard back and the motor cover front and its belonging screws were also experienced as difficult. For the motor sub-assembly the gearbox and the pivot bracket and its screws, was considered the hardest part to assemble. Additionally all the nuts in all sub-assemblies were also considered hard.

To facilitate the handling and positioning of these parts there are some common strategies and design guidelines. As noted in the BDM the thickness and size of each part affects the assembly time. However, there are other design features to take in consideration that also affect the assembly process:

1. Symmetry/asymmetry
2. Nesting
3. Tangling
4. Material and safety considerations

Motor cover front (part number: 206)

The motor cover front is a thin component with pronounced asymmetric features that facilitate easy orientation during assembly. However, due to tight tolerances and a tight fit between the motor cover front and back, the assembly process requires precise alignment. Excessive force or misalignment during handling can deform the interface between the parts, placing high demands on assembly accuracy and care.

The current design has an inner plastic guide edge that is meant to help with guidance during the assembly, see Figure 32. As the guideline looks now it is not supporting the assembly because the edge is not tall enough so it's hard to find. To make this guide edge more effective it could benefit from having a more chamfered edge as guideline on the inside, see Figure 33. That would help the part self align a lot better.

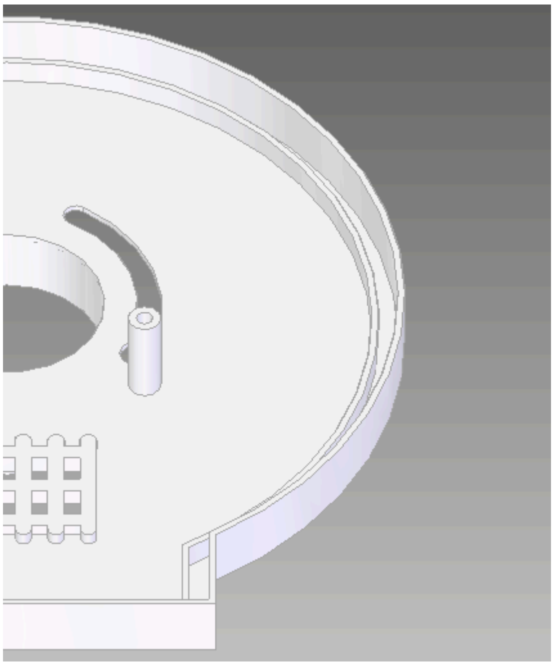


Figure 34 - Current design guideline, motor cover front

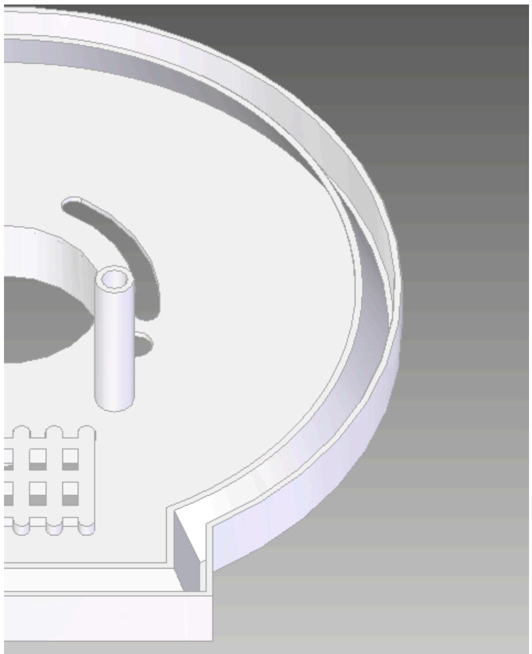


Figure 35 - Suggested design guideline, motor cover front

The screws (part number: X13) are also hard to align and position since they are supposed to fasten and match with both the motor cover front and the electromagnetic coil. This requires that both parts are perfectly aligned with each other for the screw to easily be assembled. As the current design looks like the motor cover fronts two cylinders, placed to help alignment of the screws, are not reaching all the way to the electromagnetic coil. Making those cylinders longer will make it easier to align the screws.

Mesh guard back (part number:204)

The current design of the mesh guard back looks at first sight symmetric but it is not. There is a screw hole on the edge of the part that is supposed to be facing down to enable assembly. The mesh guard back is assembled with the mesh guard front with the help of one screw, one nut and three “clamps”. To improve the mesh guard back design it's better to make it fully symmetric by adding a hole on the opposite side. To simplify the assembly between the two mech guards preferably no screws should be needed. Instead adding snap-fit pins would increase the efficiency. The snap-fit pins/tabs can be a part of either the mesh guard front or back.

Adding snap-fit pins/tabs will decrease the number of parts with two, one nut and one screw. Both of these parts were experienced as hard to align and position as well as the mesh guard back.

Gearbox

The gearbox is hard to align and position. Adding a small notch or similar friction fit to temporarily hold the gearbox in place would remove the requirement to hold down the part to keep it in the right position and if you made the guiding cylinders more chamfered it would also be easier to align and assemble.

Pivot bracket

The pivot bracket is closely integrated with both the gearbox and the neck tilter. During manual assembly, two hands are required, and the fan must be rotated to improve access. Installing the pivot bracket involves two screws and two washers, but the limited space makes it difficult to reach the fasteners with a tool. Implementing a press-fit or snap-fit design could reduce the number of components and simplify the assembly of the pivot bracket by minimizing the required axis directions and reduce the dependency of tools and tool access.

General design changes

To improve the efficiency of the manual assembly process, it's important to identify customized or non-standard components that could be replaced with standardized alternatives. For instance, if the neck tilter is secured with an M6x12 screw and the motor cover uses an M7x13 screw, this introduces unnecessary variation. Standardizing both to a common screw type (e.g., M6x12) would reduce the number of unique components, simplifying inventory management, speeding up part identification, and decreasing assembly time.

6.1.2 Results from design improvements

The direct effect these design changes have on handling and insertion time was calculated and compared with the current efficiency. As mentioned before the total handling and insertion time for the current design was estimated to be $t_{ma-total}$= 321.38 seconds, see Table XVS. Using the same reference Boothroyd Dewhurst reference time tables the new time was calculated to be $t_{ma-total_{NY}}$ = 312.88 seconds. As seen there is not the biggest difference in the total time for handling insertion. The improvement of efficiency was also small but still improved, see Table 11.

Table 10 - Comparison of total handling/insertion time and efficiency before and after design improvements.

	Before DFA improvements	*After DFA improvements*
$t_{ma-total}$	321.38 s	312.88 s
e_{ma}	43.87%	45.06%

However, it's important to note that the Boothroyd Dewhurst reference time tables may not always accurately reflect real-world assembly times. Since the process is performed manually by humans, there will naturally be variations e.g. assembly times can differ between operators depending on their level of experience.

Additionally, the efficiency index does not account for all the benefits of part reduction. Reducing the number of components not only simplifies assembly but also improves logistics such as inventory management and part transportation. Fewer parts make it easier for the plant to stay organized and help operators locate and handle components more efficiently.

It is important to also be aware of the impact some of the design changes may cause in other stages during the product's life. For example some design changes might make it harder to manufacture the part or limit the service and disassembly abilities of the product. So by adding snap-fit solutions the disassembly can become more difficult.

6.2 Design for Automated Assembly

To evaluate how suitable the product is for automated assembly, a systematic method was used according to Eskilander. The purpose of the method is to identify design problems that could prevent or make automation more difficult, for example complex geometry, the need for multiple assembly directions, or frequent tool changes.

The analysis was done on two levels, product level, where the full product structure including sub-assemblies was analyzed, and part level, where each individual component was evaluated. [18]

Each part or sub-assembly was scored with 1, 3, or 9 points depending on how well it met the criteria. The higher the total score, the better the product is suited for automated assembly. However, for some specific criteria, it was not possible to assign 3 points, the part either fulfilled the requirement or it didn't. In those cases, only 1 or 9 points were used. [18]

Design for automated assembly was calculated using the following equation:

$$Assembly\ Index_x = \frac{Total\ sum}{Maximum\ points * Number\ of\ parts} * 100\%$$

"x" shows if the index is for the part or product level. The numerator is the total score from the table, and the denominator is the maximum possible score. The result is multiplied by 100 to get a percentage.

By combining both levels of analysis, improvement areas were clearly identified that could simplify and enable automated production.

Product level

First, all sub-assemblies were identified**: Stand, Buttons, Head,** and **Motor**. Each sub-assembly was evaluated based on total number of components, number of unique components, and assembly directions (see appendix A).

The result showed that the product as a whole reached a DFA-A index of 44.4%, which indicates moderate suitability for automation. The full table can be found in appendix D.

$$Assembly\ Index_{PRODUCT} = \frac{112}{28 * 9} * 100\% = 44.4\%$$

Part level

A more detailed analysis was done at the part level. All parts in the table fan were identified and listed (see table 3). Then, each part was scored based on specific DFA criteria such as weight, size, grip, and insertion guidance (see appendix E).

The same calculation method as at the product level was used, and the result was a DFA-A index of 54.8%. This means that some components are well designed for automation, but the overall product structure still limits the potential. The complete score table can be found in appendix F. [18]

$$Assembly\ Index_{PART} = \frac{4972}{18 * 56 * 9} * 100\% = 54.8\%$$

6.2.1 Design improvements for automated assembly

This section presents selected components of the table fan that have been analyzed and improved with a focus on automated assembly. The proposed improvements are based on the DFA-A index scores presented in section 6.2. The aim is to reduce assembly complexity and increase the final DFA-A index in a redesigned version of the product.The key strategy has been to identify and improve the most critical components that negatively affect automated assembly. Through part reduction, simplified fixation methods, and functional integration, the overall product design has been made more suitable for automation, with fewer assembly steps and less handling required. We of course understand that every part in the product is important and have a reason to be a part of the product. But we would like to give some advice that might increase the DFA-A index. Below we'll represent the possible improvement to fit an automatic assembly.

Button spring

One of the most critical components according to Appendix F is the button spring. These parts received low DFA-A index scores due to poor suitability for automation. The main issues are that they are difficult to grip automatically and require very precise 3D positioning. While some springs are difficult to replace due to their mechanical role, three of them can be effectively redesigned.

A viable solution is to replace the metal springs with rubber domes, similar to those found in keyboard switches. These rubber domes would be integrated directly into the button body top part and connected to the buttons, just like in a membrane keyboard. When the button is removed, the rubber dome remains in place underneath.

This approach eliminates three critical spring components, preserves the required return functionality, and improves automation by removing separate parts. One consideration is that the button metal plate must be inserted before the button body top. This change only requires a reordering of operations and does not affect function.

Bottom plate

Another critical area identified by the Eskilander DFA table is the bottom plate. Currently, six screws are required to attach the bottom plate to the stand body. This is unsuitable for automated assembly due to the need for precise alignment and screwdriving.

This can be improved by implementing snap-fits, allowing the bottom plate to be attached quickly without tools. The machine only needs to press the plate into place until it locks. To achieve this, snap-fit features must be designed into the bottom plate, and corresponding slots added to the stand body. The feet remain as plug in parts, and their holes should be retained. Functionality remains unchanged.

The main trade off is disassembly. Special tools may be required, and it may be more difficult to remove the part manually. However, this solution improves assembly efficiency and reduces cost over time.

Power cable bracket

Another component with a relatively low DFA-A score (70) is the power cable bracket. The score is low because the part requires precise positioning and fastening with screws, which is inefficient for automation.

A proposed improvement is to use a snap fit cable clamp instead. This removes the need for screwdriving and simplifies the process. The number of parts is reduced, and the machine only needs to press the cable into place. To implement this, snap fit features can either be added to the existing bracket or the bracket can be integrated into the stand body itself. Only two snap fit points are necessary for stable cable retention.

Wire bracket

The wire bracket is another part with high automation cost. It is a small component, used three times, and serves only to hold wires in place. Each instance requires precise positioning and additional handling steps.

A more automation friendly approach is to eliminate the wire bracket entirely and instead mold a cable guide channel directly into the button body bottom. This retains the cable holding function without adding extra parts. The operator or robot only needs to place the wire into the channel. No separate assembly step is needed.

To implement this, the wire bracket part is removed from the design, and the cable channels are built into the plastic housing during molding.

6.2.2 Impact of design improvements

The main purpose with the suggested improvements is to make it more suitable for a possible automatic assembly. In this section, we will discuss the suggested design improvements by re-calculating its DFA-A index once again. By calculating the DFA-A index, we'll get to see how suitable our product is for possible automatic assembly.

By implementing the suggested improvements, we can delete the button springs from the DFA-A table. Other parts won't be affected, besides the fact that we might need to change the operations, but we deleted 3 critical parts. Then, we'll exchange the M6x12 screws with some snap fits. This means we can delete them from the table as well, and with snap fits (depending on how we design it), there will only be one way to assemble the bottom plate, therefore the score from both criteria will go from 3 to 9.

The third suggested change is to exchange the M7x12 screws for two snap fits. This means we can delete them from the DFA-A table. The part won't be fragile, which gives 9 points instead. The motions will be 2 steps, which gives 3 points instead of 1. Reachability will be 3 points instead of 1. The snap fits idea means we won't need any fastening method, any extra tools, and it will be one way to assemble it, therefore the point will be 9 instead of 1.

The last suggested improvement is that we totally remove the wire bracket. We would exchange the wire bracket with a cable guide channel. This means we can delete it from the table completely.

Table 11 - Comparison of DFA-A index between before DFA improvements and after.

	Before DFA improvements	*After DFA improvements*
Total points	4972	4696
Max possible points	9072	8424
DFA-A index	54,8%	55,7%

In the table above, we can see the new DFA index. All those changes lead to us getting 4696 points out of 8424 possible points, which is 55.7%. Compared to the old DFA-A index, it's not such a big difference, but it is more suitable for automatic assembly. [18]

We also know that some parts are critical, like the wire bracket. We also know that snap fits aren't the best solution, because they can cause some other problems. For example, disassembly will be hard. It will require a special tool to take it apart, and it will be difficult not to damage the snap fits.

Worth mentioning is that this doesn't only improve the automatic assembly, but it also optimizes the logistics by reducing and eliminating some parts.

But the focus was to make the product suitable for automatic assembly.

7. Financial analysis

A financial analysis was made to evaluate the production's feasibility, giving a clear picture of the economic sustainability. This was done by highlighting challenges and opportunities based on investment needs and potential profitability.

7.1 Breakdown

When looking at the financial aspects of the production, operational and fixed costs were considered for expenses. This is a simplified view to not go too far beyond the project scope. To account for additional expenses and unexpected events, a 7% overshoot is used in the result calculations.

Operational costs (variable costs) are made up by material and salary costs as seen in Table 12. The material cost is estimated as 30% of the product's market price, based on the assumption that material cost for electronic components are about 60% of market price [13]. The salary costs are based on average salaries for those jobs including employer's fee in Sweden [5].

Table 11. Operational costs

Cost	***Amount (SEK)***	***Comment***
Material		
Total parts	7491665,485	
Salaries		
Operators	9494568	17 operators (13 WS, 4 logistics)
Engineers	2064552	2 production / design engineers
Plant manager	1370484	1 overseeing manager
Maintenance worker	488448	1 Janitor / facility worker
Total	19854073,71	

Fixed costs are made up by facility and equipment costs, as seen in Table 13. The facility cost is based on the average cost of a warehouse in the Stockholm region [12]. The equipment costs are based on prices found in common stores.

Table 12. Fixed costs

Cost	*Amount (SEK)*	*Comment*
Facility		
Facility	11772000	Warehouse & workshop
Equipment		
Screwdrivers	24000	16 screwdrivers (13 required)
Nut driver	5400	3 nut drivers (2 required)
Shelves	87650	10 shelves for input/output

Fixtures	3664	13 vise fixtures
Total	11892714	

For capital, revenue and investments were considered. The required investment to get started was given by the fixed cost and six months of operational costs, adding up to 21453406 kr. The revenue was given by the amount of fans produced with the line's production rate multiplied by the income per fan set to 240 kr. The fan price was adjusted in order to get reasonable values to work with.

This gave the final values for net profit, ROI and payback time in years, seen in Table 14, which are used to evaluate the production's finances.

Table 13 - Result calculation for manual assembly

Selling Price (SEK)	*Net profit (SEK)*	*With 7% overshoot (SEK)*	*Req. investment*	*ROI (%)*	*Payback time (years)*
119	−4879976	−4538377,68	20431327,7	−22,2	−4,5
199	859907	799713,51	21661302,62	3,7	27,1
240	3801597	3535485,21	22291664,77	15,9	6,3

When considering production scalability, a manual assembly will have a constant cost per unit when compared to automatic assembly. This is because the cost difference is negligible on the manual side as automatic assembly requires much more investment, while cost for facility and equipment is needed for both. This results in only looking at operational cost and production volume according to the following formula:

$$C_{unit} = \frac{Operational\ cost}{Production\ volume}$$

Which gives a unit cost of 158kr for each table fan.

7.2 Alternative scenario (automatic assembly)

For the automatic scenario, the top line (operations 1-17) is adjusted by introducing cobots (collaborative robots) in a partially automated assembly. The top line then decreases the required number of operators from 6 to 4 by replacing it with 3 cobots. A cobot typically costs around 400000kr, which increases the fixed costs by 12000000kr, but decreases the annual operational costs with 2 operator salaries. Giving the result calculations as seen in Table 15.

Table 14 - Result calculation for automatic assembly

Selling Price (SEK)	*Net profit (SEK)*	*With 7% overshoot (SEK)*	*Req. investment*	*ROI (%)*	*Payback time (years)*
240	4918605	4574302,65	33733160,77	13,6	7,4

7.2 Discussion

When doing the financial analysis the original selling price of 119 kr was used at first, however this gave a negative annual net profit. The main factor for this was the high costs of Swedish salaries needed for manual assembly. To adjust this as well as including a safety margin (overshoot), the selling price was increased to 240 kr (excl. VAT) which is still a reasonable price for a table fan of that size.

Since the selling price had to be increased, it was tuned to give a reasonable return on investment (ROI) of 15,9% and payback time of 6,3 years while still not being unrealistically expensive for the Swedish market. For a small to medium sized manufacturing business, ROI should land in the interval of 16%-33% [9] and a payback time of 1-3 years [6]. This shows that the production has a poor but not impossible financial performance to work with.

To develop a better financial performance, the production could implement the optimized DFA designs to optimize the flow and lower cycle times, use automation which require less operators, and possibly increase market share to sell more products. An improved design could maybe also justify an increased price, leading to more profit. There is also a possibility to move production to another country with lower salaries, which probably is the current case for the original fan price.

An attempt was made to use partial automatic assembly instead of manual assembly. However, using the same selling price of 240kr as for the manual assembly scenario, both the ROI and the payback time got worse in comparison. This made it clear that it is a worse option and was not considered further.

If the salaries in China are assumed to be 40% lower than in Sweden, then by only decreasing the salaries in the analysis, the selling price could in turn be decreased from 240 kr to 155 kr to get the same ROI and payback time. This of course excludes material costs and fixed costs for facility and equipment which would make it closer to the original price, but also shipping which a table fan produced in Sweden will save money on.

8. Sources

1. Arbetsdagar per år. (n.d.). *Arbetsdagar per år*. Available at: https://xn--arbetsdagarperr-ulb.se/en/.
2. Biltema. (2025). *Table fan 23 cm*. Available at: https://www.biltema.se/en-se/home/fans-and-indoor-climate/table-fans/table-fan-23-cm-2000042183.
3. Brainly. (n.d.). *Question 33293008*. Available at: https://brainly.com/question/33293008.
4. Findresearcher.sdu.dk. (n.d.). *8portal*. Available at: http://8portal.findresearcher.sdu.dk.
5. Jobbland. (2025). *Lönestatistik Juni, 2025*. Available at: https://jobbland.se/lon
6. LeanManufacture.net. (n.d.). *Payback Period KPI*. Available at: https://www.leanmanufacture.net/kpi/paybackperiod/.
7. Machine Design. (2022). *A History of Design for Manufacturing and Assembly*. Available at: https://www.machinedesign.com/automation-iiot/article/21213546/a-history-of-design-for-manufacturing-and-assembly.
8. Monetti, F.M. and Maffei, A. (2025). *Design for Assembly – Automatic*. [PowerPoint presentation]. KTH Royal Institute of Technology.
9. Morgan & Westfield. (n.d.). *Business Valuation: Return on Investment (ROI)*. Available at: https://morganandwestfield.com/knowledge/business-valuation-return-on-investment-roi/.
10. Next Plus. (2023). *10 Lean Manufacturing Tips to Boost Assembly Line Efficiency*. Available at: https://nextplus.io/lean-manufacturing/10-lean-manufacturing-tips-to-boost-assembly-line-efficiency/.
11. Scopus. (2017). *Design for Assembly (DFA) and Table Fan Study*. Available at: https://www-scopus-com.focus.lib.kth.se/record/display.uri?eid=2-s2.0-85034772040.
12. Smart Pattern Making. (n.d.). *Understanding Time Measuring Unit (TMU) Standard Time and Motion Study*. Available at: https://www.smartpatternmaking.com/blogs/articles/understanding-time-measuring-unit-tmu-standard-time-and-motion-study.
13. Statista. (2024). *Average purchase price of warehouses in Sweden, by region*. Available at: https://www.statista.com/statistics/1154332/average-purchase-price-of-warehouses-in-sweden-by-region/.
14. Titoma. (2022). *Reducing Production Cost*. Available at: https://titoma.com/blog/reducing-production-cost/#h-3-the-material-makes-up-60-of-nbsp-your-product-cost-nbsp.
15. Verified Market Reports. (n.d.). *Table Fans Market*. Available at: https://www.verifiedmarketreports.com/product/table-fans-market/.
16. Weber USA. (n.d.). *Product: Feeding Systems - Profile Feed Tubes for Special Materials*. Available at: https://www.weberusa.com/product-feeding-systems-profile-feed-tubes-for-special-materials.

17. Weber USA. (n.d.). *Product: Fixtured Screwdrivers - SEV-C for Human-Robot Collaboration*. Available at: https://www.weberusa.com/product-fixtured-screwdrivers-fixtured-screwdriver-sev-c-for-human-robot-collaboration.
18. Weber USA. (n.d.). *Product: Inserting Systems - Fixtured Insertion System PEB*. Available at: https://www.weberusa.com/product-inserting-systems-fixtured-insertion-system-peb.
19. Tran, B.Q. (2025). *Robotic Arm Trends: Size, Speed, and Application Data*. Available at: https://patentpc.com/blog/robotic-arm-trends-size-speed-and-application-data

9. Appendix

A -

Scoring for each part with regards to automated assembly

Score 1	Total number of parts
Score 2	Proportion of unique parts
Score 3	Does the sub-assembly include a base part?
Score 4	Does the base part require multiple fixtures during assembly?
Score 5	Total number of assembly directions for the base part
Score 6	Possibility of parallel assembly operations?
Score 7	Presence of tolerance chains affecting the assembly process

B -

Boothroyd Dewhurst method determining essential and nonessential parts.

Part Number	Sub-Assembly	Name	**Must be of different Material**	**Moves relative to all other items**	**Seperate to allow assembly**
X01	Fastener	Screw M9x33	TRUE	TRUE	TRUE
X02	Fastener	Nut 10mm	FALSE	FALSE	TRUE
101	Stand	Feet	TRUE	FALSE	FALSE
X03	Fastener	Screw M6x12	FALSE	FALSE	TRUE
102	Stand	Bottom plate	FALSE	FALSE	TRUE
X04	Fastener	Screw M7x12	FALSE	TRUE	FALSE
103	Buttons	White button	FALSE	TRUE	FALSE
104	Buttons	Grey button	FALSE	TRUE	FALSE
105	Buttons	Black button	FALSE	TRUE	FALSE

106	Buttons	White push pin	TRUE	TRUE	FALSE
107	Buttons	Button spring	TRUE	TRUE	FALSE
108	Buttons	Button metal plate	TRUE	TRUE	FALSE
109	Buttons	Button body top	TRUE	FALSE	TRUE
110	Buttons	Spring metal plate	TRUE	FALSE	FALSE
111	Buttons	Wire bracket	TRUE	FALSE	FALSE
112	Buttons	Speed 1 or 2 plate	FALSE	TRUE	FALSE
113	Buttons	Lock button spring	FALSE	TRUE	FALSE
114	Buttons	Button lock plate	FALSE	TRUE	FALSE
115	Buttons	Button unlock plate	TRUE	FALSE	TRUE
116	Buttons	Button body bottom	TRUE	FALSE	TRUE
X05	Fastener	Screw M7x12	FALSE	FALSE	FALSE
117	Stand	Power cable bracket	FALSE	FALSE	FALSE
X06	Fastener	Screw M6x8	FALSE	FALSE	FALSE
118	Stand	Plastic wire box	FALSE	FALSE	FALSE
119	Stand	Power cable	TRUE	FALSE	FALSE
120	Stand	Stand body	FALSE	FALSE	TRUE
X07	Fastener	Screw M4x11	FALSE	TRUE	TRUE
X08	Fastener	Nut 5mm	FALSE	TRUE	TRUE
X09	Fastener	Screw M8x8	FALSE	FALSE	FALSE
X10	Fastener	Spacer 12mm	FALSE	FALSE	FALSE
201	Head	Plastic cover	FALSE	FALSE	FALSE
202	Head	Mesh guard front	FALSE	FALSE	TRUE
203	Head	Propeller	FALSE	TRUE	FALSE
X11	Fastener	Plastic nut 40mm	FALSE	TRUE	FALSE
204	Head	Mesh guard back	FALSE	FALSE	TRUE
X12	Fastener	Screw M6x12	FALSE	TRUE	FALSE
205	Motor	Rotation button	FALSE	TRUE	FALSE
X13	Fastener	Screw M7x21	FALSE	FALSE	TRUE
206	Motor	Motor cover front	FALSE	FALSE	TRUE
X14	Fastener	Screw M7x13	FALSE	FALSE	TRUE
207	Motor	Motor cover back	FALSE	FALSE	TRUE
X15	Fastener	Screw M6x12	FALSE	TRUE	FALSE
X16	Fastener	Screw M10x12	FALSE	FALSE	FALSE

X17	Fastener	Black spacer	TRUE	TRUE	FALSE
X18	Fastener	Screw M10x12	FALSE	FALSE	FALSE
X19	Fastener	Black spacer	TRUE	FALSE	FALSE
208	Motor	Pivot bracket	FALSE	TRUE	FALSE
209	Motor	Neck tilter	FALSE	TRUE	TRUE
X20	Fastener	Screw M6x35	FALSE	FALSE	TRUE
210	Motor	Gearbox	FALSE	TRUE	FALSE
211	Motor	Shaft bracket	FALSE	TRUE	TRUE
212	Motor	Electric rotor	FALSE	TRUE	FALSE
X21	Fastener	Screw M6x27	FALSE	FALSE	TRUE
X22	Fastener	Nut 7mm	FALSE	FALSE	TRUE
213	Motor	Neck connector	FALSE	TRUE	FALSE
X23	Fastener	Plastic spacer 12mm	TRUE	FALSE	FALSE
214	Motor	El, mag, Coil	TRUE	TRUE	TRUE

C -

DFA manual assembly (orange rows are the parts that was affected by the suggested DFA improvements).

Part Number	Sub-Assembly	part	Ability to align	**Insertion index**	**Handling Index**		
X01	Fastener	Screw M9x33	easy	3,5	Part added not secured Not easy to align resistance to insertion Easily reach	1,5	One hand
X02	Fastener	Nut 10mm	hard	6	Part secured immeideatly Tighten Easy to align	2,17	One hand
101	Stand	Feet	easy	7	Part secured immeideatly Plastic def riveting easy to align easy reach	1,5	One hand
X03	Fastener	Screw M6x12	easy	6	Screw tighten immeidatly easy to align easy reach	1,5	One Hand

102	Stand	Bottom plate	easy	1,5	Not added not secured no holding down required easy align easy reach	4,1	Two hands
X04	Fastener	Screw M7x12	hard	6	Part secured Immediatly Screw tighten easy align easy reach	2,9	One hand
103	Buttons	White button	easy	2	part secured immideatly press-fit Easy algin easy reach	2,25	One hand
104	Buttons	Grey button	easy	2	part secured immideatly press-fit Easy algin easy reach	2,25	One Hand
105	Buttons	Black button	easy	2	part secured immideatly press-fit Easy algin easy reach	2,25	One Hand
106	Buttons	White push pin	hard	4,5	Part secured immideatly press-fit easy to align restricted access	3,06	One Hand
107	Buttons	Button spring	easy	1.5	Part added not secured no holding down required easy to align no resistance easy reach	5	Two hands
108	Buttons	Button metal plate	easy	4	Part added not secured no holding down required easy to align no resistance obstructed access	5	Two hands
109	Buttons	Button body top	easy	2	Part secured immediatly press-fit easy to align easy access	4,1	Two hands
110	Buttons	Spring metal plate	hard	5	Part added not secured not easy to algin no resistance obstructed access	3,06	One hand

111	Buttons	Wire bracket	easy	5	Part added not secured not easy to algin no resistance obstructed access	2,25	One hand
112	Buttons	Speed 1 or 2 plate	easy	4	Part added not secured no holding down required easy to align no resistance obstructed access	2,51	One hand
113	Buttons	Lock button spring	easy	1,5	"Part added not secured no holding down required easy to align no resistance easy reach"	5,25	Two hands
114	Buttons	Button lock plate	easy	4	Part added not secured no holding down required easy to align no resistance obstructed access	3	One hand
115	Buttons	Button unlock plate	easy	4	Part added not secured no holding down required easy to align no resistance obstructed access	2,85	One hand
116	Buttons	Button body bottom	easy	2	Part secured immediatly press-fit easy to align easy access	2,25	One hand
119	Stand	Power cable	easy	1,5	Part added not secured easy align no resistance easy access	1,13	One hand
120	Stand	Stand body	easy	2,5	Part added not secured no holding down required not easy align no resistance easy access	4,1	Two hands
X07	Fastener	Screw M4x11	hard	6	part added not secured no holding dow required not easy to align resistance obstructed access	3,18	One hand

X08	Fastener	Nut 5mm	hard	10	part secured immediatly screw tighten easy to align obstructed access and restricted vision	2,18	One hand
202	Head	Mesh guard front	easy	8	Part added but secured holding down required not easy to align no resistance easy access	4,1	Two hands
203	Head	Propeller	Easy	1,5	Part added not secured no holding down required easy to align no resistance easy access	1,5	One hand
X11	Fastener	Plastic nut 40mm	easy	6	Part secured immediatley screw tightening easy to align easy access	1,5	One hand
204	Head	Mesh guard back	hard (bad assymetric)	Before (2,5) After 2	**Before** Part added not secured no holding down not easy to align no resistance easy access **After** (Part secured Immediatly snap-fit/press-fit easy to align easy access)	4,1	Two hands
X12	Fastener	Screw M6x12	Easy	8,5	part secured immediatly screw tighten easy align obstructed access	1,8	One hand
205	Motor	Rotation button	Easy	1,5	Part added not secured no holding down easy align no resistance easy access	1,5	One hand
X13	Fastener	Screw M7x21	Easy	Before 8 After	**Before** Part secured immediatly hard to align easy access **After** Part secured immediatly	1,5	One hand

				6	screw tighten easy to align easy access		
206	Motor	Motor cover front	Hard	Before 2,5 After 1,5	**Before** Part added not secured no holding down required not easy align no resistance easy access **After** Part added not secured no holding down required easy align no resistance easy access	2,73	One hand
X14	Fastener	Screw M7x13	Hard	8,5	Part secured immediatly screw tighten easy t align obstructed access	2,57	One hand
207	Motor	Motor cover back	Easy	2,5	Part added not secured no holding down not easy to align no resistance easy access	5	Two hands
X15	Fastener	Screw M6x12	Easy	6	Part secured immediatly screw tighten easy align easy access	1,8	One hand
X17	Fastener	Black spacer	Easy	1,5	Part added not secured no holding down easy align no resistance easy access	1,69	One hand
208	Motor	Pivot bracket	Hard	Before 9 After 4,5	**Before** Part added not secured holding down required not easy to align no resistance obstructed access **After** Part secured immediatly snap-fits easy to align hard access	5	Two hands

209	Motor	Neck tilter	Easy	1,5	Part added not secured no holding down required easy align no resistance easy access	1,95	One hand
X20	Fastener	Screw M6x35	Easy	8	Part added secured immediatly screw tightening not easy to align easy access	1,5	One hand
210	Motor	Gear box	Hard	Before 6,5 After 1,5	**Before** Part added not secured holding down required not easy to align no resistances easy access **After** Part added not secured no holding down required easy to align no resistances easy access	4,1	Two hands
211	Motor	Shaft bracket	Easy	5,5	Part added not secured holding down required easy to align no resistance easy access	4,1	Two hands
212	Motor	Electric rotor	Easy	1,5	Part added not secured no holding down easy to align no resistance easy access	1,5	One hand
X21	Fastener	Screw M6x27	Easy	6	Secured immediatly screw tighten easy to align easy access	1,5	One hand
X22	Fastener	Nut 7mm	Hard	7,5	Part secured immediatly Screw tightening Easy to align Easy access	2,17	One hand
213	Motor	Neck connector	Easy	1,5	Part secured immediatly Easy to align Part and associated tool can easily reach	2,25	One hand

X23	Fastener	Plastic spacer 12mm	Easy	1,5	Part added but not secured No holding down Easy to align No resistance	1,43	One hand
214	Motor	El, mag, Coil	Easy	1,5	Part added but not secured Holding down Not easy to align No resistance to insertion	2,25	One hand

D -

DFA-A calculation for product-level.

Sub assembly	Score 1	Score 2	Score 3	Score 4	Score 5	Score 6	Score 7	Sum
Fan head	9	1	9	3	1	3	1	27
Stand	3	3	9	9	9	1	1	35
Button	3	3	9	9	3	3	1	31
Motor	3	1	9	3	1	1	1	19
							Total sum	112

E -

Assembly evaluation criteria for DFA-A

Score 1	Need to assemble?
Score 2	Level of defects
Score 3	Orientation
Score 4	Non-fragile parts
Score 5	Hooking
Score 6	Center of gravity
Score 7	Shape
Score 8	Weight
Score 9	Length
Score 10	Gripping
Score 11	Assembly motions

Score 12	Reachability
Score 13	Insertion
Score 14	Tolerances
Score 15	Hold assembled parts
Score 16	Fastening method
Score 17	Joining
Score 18	Check/adjust

F -

DFA-A index calculation for part level

Name	Score 1	Score 2	Score 3	Score 4	Score 5	Score 6	Score 7	Score 8	Score 9	Score 10	Score 11	Score 12	Score 13	Score 14	Score 15	Score 16	Score 17	Score 18	**Sum**
Screw M9x33	9	9	1	9	9	1	3	9	9	3	3	9	3	1	9	3	3	3	**96**
Nut 10mm	9	9	1	9	9	3	9	9	9	1	3	9	3	1	9	3	3	3	**102**
Feet	9	3	1	3	9	3	3	9	9	1	9	9	9	9	9	9	9	9	**122**
Screw M6x12	9	9	1	9	9	1	3	9	9	3	3	9	3	1	9	3	3	3	**96**
Bottom plate	9	3	3	3	9	1	1	9	1	1	1	9	3	3	3	3	3	3	**68**
Screw M7x12	9	9	1	9	9	1	3	9	9	3	3	9	3	1	9	3	3	3	**96**
White button	9	3	1	3	9	3	1	9	9	3	3	3	1	9	9	9	9	3	**96**
Grey button	9	3	1	3	9	3	1	9	9	3	3	3	1	9	9	9	9	3	**96**
Black button	9	3	1	3	9	3	1	9	9	3	3	3	1	9	9	9	9	3	**96**
White push pin	9	3	1	9	9	1	1	9	9	1	1	3	1	3	3	9	9	1	**82**
Button spring	9	1	1	3	1	1	3	9	9	1	1	1	1	1	1	3	3	1	**50**
Button metal plate	9	3	1	9	1	1	1	9	9	3	9	3	3	3	3	9	9	1	**86**
Button body top	9	3	3	3	1	1	1	9	3	3	3	3	3	3	9	9	3	3	**72**

Spring metal plate	9	1	1	3	1	1	1	9	9	3	9	3	1	3	3	9	9	3	**78**
Wire bracket	9	3	1	3	1	3	1	9	9	3	3	3	1	9	3	9	9	3	**82**
Speed 1 or 2 plate	9	3	1	9	9	1	1	9	9	3	9	3	1	3	3	9	3	3	**88**
Lock button spring	9	1	1	3	1	1	9	9	9	1	1	1	1	1	1	3	3	1	**56**
Button lock plate	9	3	1	9	1	1	1	9	9	3	3	3	3	3	3	9	3	1	**74**
Button unlock plate	9	3	1	9	9	9	1	9	9	3	9	9	1	9	3	9	9	3	**114**
Button body bottom	9	3	3	3	9	3	1	9	3	9	3	9	3	3	9	9	3	3	**94**
Screw M7x12	1	9	1	9	9	1	3	9	9	3	3	9	3	1	9	3	3	3	**88**
Power cable bracket	1	9	1	1	9	3	1	9	9	3	3	9	1	1	1	3	3	3	**70**
Screw M6x8	1	9	1	9	9	1	3	9	9	3	3	9	3	1	9	3	3	3	**88**
Plastic wire box	1	9	3	3	9	3	9	9	9	3	3	9	3	3	3	3	9	3	**94**
Power cable	9	9	3	3	9	3	9	9	1	9	9	9	3	3	1	3	3	3	**98**
Stand body	9	3	9	1	9	1	1	9	1	3	1	9	9	3	3	3	3	3	**80**
Screw M4x11	9	9	1	9	9	1	3	9	9	3	3	9	3	1	9	3	3	3	**96**
Nut 5mm	9	9	1	9	9	3	9	9	9	1	1	3	3	1	9	3	3	3	**94**
Screw M8x8	1	9	1	9	9	1	3	9	9	3	3	9	3	1	9	3	3	3	**88**
Spacer 12mm	1	9	1	3	9	9	9	9	9	1	9	3	3	3	1	3	3	3	**88**
Plastic cover	1	3	1	1	9	3	3	9	3	1	3	9	1	3	3	3	3	3	**62**

Mesh guard front	9	3	3	3	9	3	1	9	1	3	3	9	1	9	3	3	3	3	**78**
Propeller	9	3	3	3	9	1	3	9	1	1	3	9	3	3	3	9	3	1	**76**
Plastic nut 40mm	9	9	1	9	9	1	3	9	9	1	3	9	3	3	9	3	3	3	**96**
Mesh guard back	9	3	3	3	9	3	1	9	1	3	3	9	1	9	3	3	3	3	**78**
Screw M6x12	9	9	1	9	9	1	3	9	9	3	3	9	3	1	9	3	3	3	**96**
Rotation button	9	3	1	9	9	1	3	9	9	3	9	9	3	3	9	3	3	3	**98**
Screw M7x21	9	9	1	9	9	1	3	9	9	3	3	3	3	1	9	3	3	3	**90**
Motor cover front	9	3	3	3	1	1	1	9	1	1	9	9	3	3	9	3	3	3	**74**
Screw M7x13	9	9	1	9	9	1	3	9	9	3	3	9	3	1	9	3	3	3	**96**
Motor cover back	9	3	3	3	1	3	1	9	3	3	3	9	1	9	3	9	3	3	**78**
Screw M6x12	9	9	1	9	9	1	3	9	9	3	3	3	3	1	9	3	3	1	**88**
Screw M10x12	9	9	1	9	9	1	3	9	9	3	3	3	3	1	9	3	3	3	**90**
Black spacer	9	9	1	9	9	9	9	9	9	1	9	9	1	3	1	3	3	3	**106**
Screw M10x12	9	9	1	9	9	1	3	9	9	3	3	3	3	1	9	3	3	3	**90**
Black spacer	9	9	1	9	9	9	9	9	9	1	9	9	1	3	1	3	3	3	**106**
Pivot bracket	9	3	1	9	9	3	1	9	3	1	1	3	1	1	3	3	3	3	**66**
Neck tilter	9	3	3	9	9	1	1	9	3	9	1	1	3	3	3	3	3	3	**76**
Screw M6x35	9	9	1	9	9	1	3	9	9	3	3	9	3	9	9	3	3	3	**104**
Gearbox	9	9	3	3	9	1	1	9	3	9	3	3	1	3	9	3	3	3	**84**

Shaft bracket	9	9	1	9	9	3	1	9	3	1	1	3	3	3	9	3	3	3	**82**
Electric rotor	9	9	3	9	9	1	3	9	3	1	3	3	1	9	3	3	3	3	**84**
Screw M6x27	9	9	1	9	9	1	3	9	9	3	3	9	3	9	9	3	3	3	**104**
Nut 7mm	9	9	1	9	9	3	9	9	9	1	1	9	3	1	9	3	3	3	**100**
Neck connector	9	3	3	3	1	1	1	9	3	3	3	3	9	1	3	3	3	3	**64**
Plastic spacer 12mm	9	9	1	9	9	9	9	9	9	1	9	3	1	3	1	3	3	3	**100**
El, mag, Coil	9	9	3	9	9	1	1	9	3	1	1	3	1	1	9	3	3	3	**78**