Assignments 1: System description specifications, evaluation criteria and target values

To gather the requirements we needed for the development of the project we followed what's called the Quality Function Deployment (QFD). The name refers to a process and a set of tools used to effectively define customer requirements and convert them into detailed engineering specifications and plans to produce the products that fulfill those requirements. The tool we mainly used is the "House of Quality", which steps are clearly described on the slides presented at the beginning of the course. Here below we report what we collected following those steps and the guidelines for the study of our specific product: the Drag Reduction System (DRS) for racing cars.

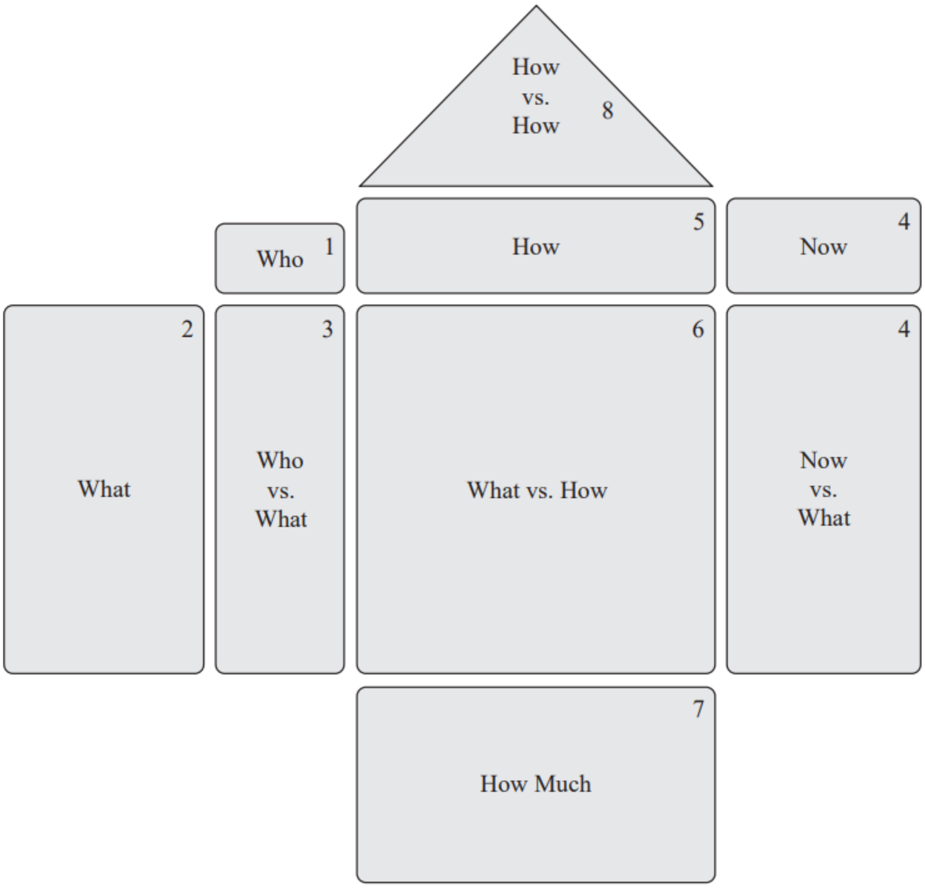


Fig. 1: the QFD diagram. Each "room" is filled following the corresponding step.

Because of the way the project was structured, we did not interact directly with the customers of our product. In a real application we would have had to deal with customers through research, surveys and focus groups. In our case, we only relied on the first method. In any case, the customers that the product must satisfy are those suggested by the professor. We briefly describe them here to make explicit what is reported in the House of quality.

Internal groups (engine, aerodynamic and mechanical teams)

The term group refers to each of the teams of the stable. The different teams are to be considered the main customers to satisfy as they include both the engineers that dictate the requirements our object have to respect (energy consumption, aerodynamics constraints etc) and those who will then work with it in practice. For our purpose, we can identify the three main groups reported here below, together with their main functionalities:

- engine team, in charge of managing the energy consumption of the motor and monitoring its performances;
- aerodynamics team, in charge of shaping the vehicle and analyze its aerodynamic properties;

- mechanical team, in charge of designing the chassis, the structure of the vehicle and all the mechanisms used for transmitting motion (in particular, for this project, the DRS actuator).

FIA
The Fédération Internationale de l'Automobile is the governing body for many auto racing events and in particular the one we are interested in: the Formula One. The rules imposed by it have to be respected so that a vehicle can compete without being banned or losing points. This is why the FIA plays a key role as a customer. Talking about the DRS, the FIA is the organization that decides when it can be used and the restrictions that the mechanism have to respect. More details will be provided later.

Pilot
This is the final user of our mechanism. Our aim is to possibly take into account its requirements to make the use of the mechanism as functional as possible in order to maximize performance.

As requested, in this assignment we will only focus on the purely technical requirements, leaving out those necessary to comply with the rules imposed by the FIA and those more related to the production of the mechanism (while keeping in mind feasibility).

Step 2: customer requirements

Functional performance

1. The DRS quickly switches between open and closed positions. (spoken)
2. The change of state of the DRS happens without residual vibrations. (expected)
3. The force of the actuators of the DRS wins the external forces acting on it. (expected)
4. The DRS uses as little energy as possible (expected).
5. The DRS disturbs as little as possible the aerodynamics (expected).

Reliability

6. Failures are not allowed (exciting).
7. The DRS is capable of working with any environment conditions (expected).

Life-cycle concerns

8. The DRS is easy to install and disassemble (exiting)
9. The DRS is easy to maintain and repair (maybe better to change it as FIA does not set constraints, you can change it as many times you want) (exiting)

Resource concerns

10. The DRS is made of standard parts (unspoken)

Manufacturing requirements

11. The DRS is resistant to high forces and high vibrations acting on the vehicle (expected).
12. The DRS weighs little (expected).

Step3: relative importance of requirements

Initially, after reviewing the possible ways to approach this step, we opted for the "weighted matrix". With it, each requirement had a weight of about 11 or 12 points, derived from its "victory" against the others each time we considered it from the point of view of the customer more interested in it. This result was not so meaningful and, comparing ourselves with the professor, we preferred to adopt the "fixed sum method". As described in the book, this method involves each client rating the various requirements with points, the sum of which must be at most 100. The advantage of this method is that clients are forced to rate some of the requirements low if they want others to have a high score, thus highlighting the aspects they need to focus on. We implemented this method putting ourselves in place of the three customers who will then have to work with the actuator (the three engineering teams). The results are reported in table form here below.

	How important is it <x> if <y>?	Engine team	Aerodynamic team	Mechanical team	Totals
1	The DRS quickly switches between open and closed positions.	8	14	12	**34**
2	The change of state of the DRS happens without residual vibrations.	8	14	16	**38**
3	The force of the actuators of the DRS wins the external forces acting on it.	10	8	25	**43**
4	The DRS uses as little energy as possible.	30	5	7	**42**
5	The DRS disturbs as little as possible the aerodynamics.	9	30	2	**41**
6	Failures are not allowed.	10	8	6	**24**
7	Capable of working with any environment conditions.	5	4	5	**14**
8	Easy to install and disassemble	3	2	2	**7**
9	Easy to maintain and repair.	0	2	2	**4**
10	The DRS is made of standard parts.	2	2	2	**6**
11	The DRS is resistant to the forces and vibrations acting on the vehicle.	6	6	10	**22**
12	The DRS weighs little.	9	5	11	**25**
	Customers totals:	100	100	100	

Step 4: identify and evaluate competitors

We discovered that this step is really challenging at the beginning of the process development, since the literature on the mechanism is scarce.
The first idea we followed was to consider as competitors the different teams participating in the competition. We soon understood that it was impossible to gather any information about the different systems adopted by them, so we discarded the idea.
Another approach that we considered was to carry out a comparison between the possible models of actuators, comparing those coming from different companies. More in detail, the type of actuators we took into consideration were: hydraulic, pneumatic and electric. After some research, we came to the conclusion that the most suitable actuator type for this mechanism is the hydraulic one. As a matter of fact, hydraulic actuators are able to produce almost instantaneous high forces and speed, and this is key in an application where every tenth of a second matters. Electrical actuators are technically scalable for any force requirement and they are even more controllable and accurate, but the electrical motors must be close to the actuator itself and the size of the motor would be significant. This is inadequate if we consider the aerodynamics of the system, while the hydraulic pump can be hidden inside the chassis of the vehicle.
Given that, we started looking for the different companies that produce hydraulic actuators for Formula One. Online there is not much to be found and we ended up discovering that the main actuators provider is a

company called Moog, so we did not find a way to compare different companies' solutions. Therefore, we concluded that the best way we could proceed was to assume that we know a priori the best actuator we can use in our system, thinking about it as a choice made by another team (the same reasoning applied for the wings). In the end, the main focus of the course is to study mechanical systems, so the idea followed in this project from now on is to study the behavior of the different possible mechanical configurations.

To have a general idea of the forces in play we have conducted a very brief study in the initial configuration, here are reported the drawings:

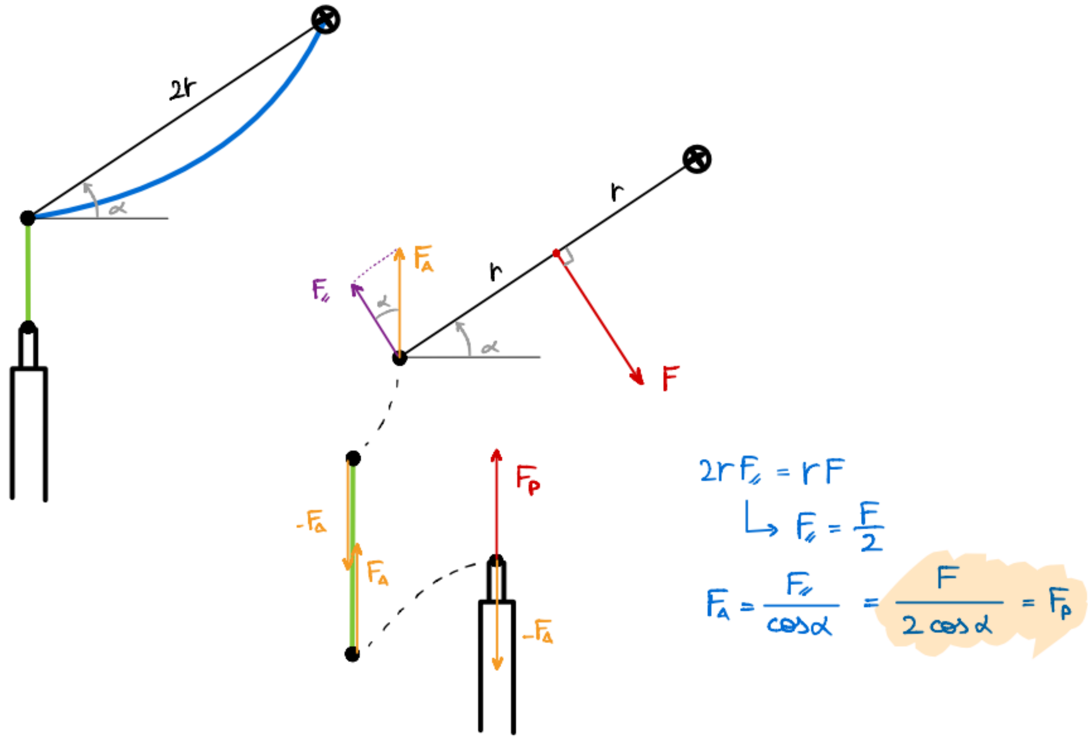


Fig. 2: push up mechanism

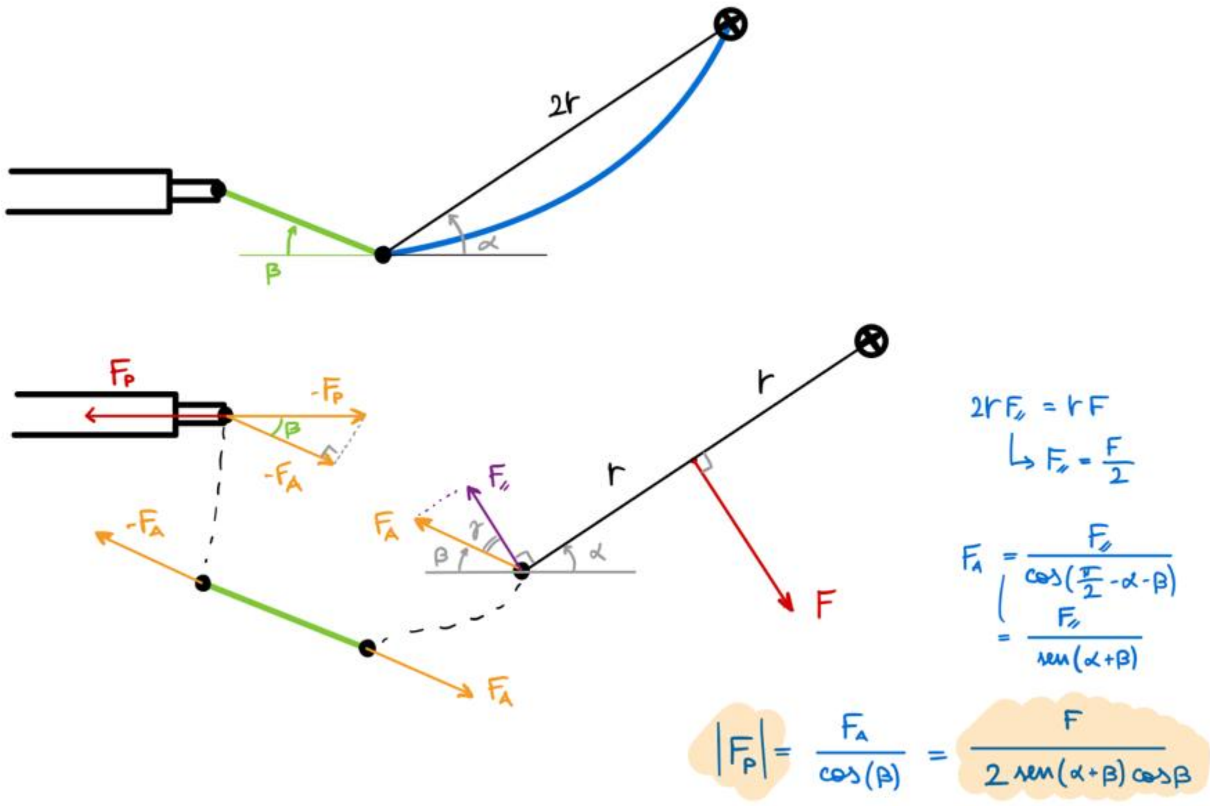


Fig. 3: pod-pull type mechanism

Although there are several simplifications and we are only looking at a snapshot of the initial configuration, these schemes give an idea of the possible forces that our hydraulic system has to develop in order to move the rear wing. Under strong simplifications and constraints, the equations show that, once the initial angle of the rear wing is chosen (angle alpha, the push mechanism requires less actuator force than the pull system. We are aware of the approximations we are doing right now, but this step was intended just to give a more "technical" tone to something we could have done using intuition only. We reserve the right to modify these initial statements in the next weeks when we'll conduct a more precise cinematic and dynamic analysis using dedicated software.
The rocker system has not been taken into account because its structure is full of variables that would make the comparison with the other mechanisms far more complicated. However, through research, we managed to find that, thanks to its levers, the overall force required to move the wing in this last mechanism is less.

Thanks to the considerations stated above and further information found on other sources, we managed to assess the competitors as shown in our HOQ. For each requirement, we briefly report here the reasoning done (the list number and the requirement number match).

1. For this requirement we have considered the piston stroke necessary to open the mechanism: it seems that, thanks to a system of levers, the piston in the pod & rocker mechanism has to cover the shortest possible distance. Next comes the push-up mechanism and finally the pod-pull one.
2. The rocker is the mechanism that requires the least force, so we believe that the vibrations on it are the least of the three competitors. In second place is the pod-pull mechanism, as the force is exerted horizontally, where the system is less prone to vibration (which usually occurs vertically).
3. From the paper provided by the professor we've inferred that the pod-rocker, thanks to its advantageous lever, requires less force from the actuator. The same goes for the push-up, option, since it applies the force at a better angle with respect to the pod-pull option
4. Given the orders chosen in the time and forces requirements, also this point follows the same order.
5. From the paper proposed by the professor we can infer that the best performing in terms of aerodynamic disturbance is the pod-pull, while the other two behave more or less the same
6. Since all these options are commonly used in F1 races they are all very reliable.
7. Since all these options are commonly used in F1 races they all behave very well in all environment conditions.
8. Because of its intrinsic complexity, the pod-rocker option is surely the more complex to maintain and repair. Since the pod-pull is higher above and outside the car chassis we can infer that it is also easier to repair than the pod-push.
9. For this assessment we applied the same reasoning of the previous point.
10. It is not feasible to directly measure how "standard" the parts of the three mechanisms are, so we assumed that, in terms of components, the pod-rocker system is the most complex one, while the push-up is the easiest.
11. Out of the three mechanisms, pod-rocker seams the steadier since it has an additional joint. Immediately after, in terms of performance and reliability, we put the pod-pull since the push-up seems to have a weaker connection with the body of the car.
12. Although the difference is minimal, looking at the mechanisms, we thought that the pod-rocker and the pod-pull are the heavier out of the three since the first one is made up of more parts and the second needs a structure to hold it. We figured that the push-up option is the lightest since it is partially included inside the body of the car.

Step 5: generate engineering specifications

Here we report the engineering specifications of our product classified according to their characteristics. At the end of the list we explain the motivation for certain choices (i.e. exclusion of the power from the list) and express our doubts about certain specifications that we think are necessary (such as whether a component is standard or not).

Functional performance

1. Opening mechanism time [ms]

2. Residual vibration frequency of the mechanism [Hz]
3. Residual amplitude frequency of the mechanism [mm]
4. Force of the actuator [N]
5. Energy consumed by the actuator [J]
6. Drag coefficient of the entire mechanism [1]

Reliability

7. Mean time between failures [hours]

Life-cycle concerns

8. Steps required to install and disassemble the mechanism [#]
9. Time required to repair the mechanism [days]

Resource concerns

10. Suppliers of the rarest component [#]

Manufacturing requirements

11. Maximum sustainable load [N]
12. Maximum operating humidity [g/m^3]
13. Maximum operating temperature [° C]
14. Maximum operating vibration frequency [Hz]
15. Maximum operating vibration amplitude [mm]
16. Mechanism mass [g]

Additional notes:

- Why did we exclude the power?
  Considering the motion of the mechanism itself, the quantities involved are time, the force to be overcome, the actuator force, the actuator power and the energy consumed. These quantities are obviously closely related and it will be our task to study how they interact with each other through model simulation. For now, we think that the specifications we will focus on are those listed above. As can be seen, we are excluding power from this list. The reason for this exclusion is that, in our opinion, the way we have set up the project in the previous steps, power does not play a role as a specification, but rather as a parameter given a priori. The doubt regarding its presence or otherwise came to us when we asked ourselves the question "Is this specification a quantity to be maximized or minimized?", to define the direction of the arrow in the final diagram. In our opinion, there is no right answer, simply the actuator must have sufficient power to generate the force we need to open the mechanism. The quantities to be minimized are for sure the opening time and the energy consumed, as also written in the project description. Our hypothesis for this project is to have an actuator capable of supplying us with the power we need. The value of this power will be determined in the simulation phase. Obviously, if we will notice that the resulting value is excessive compared to what the actuators on the market can offer, we will study the system by placing limitations on the power.
- How to measure how much a component is standardized?
  One of the requirements we thought of in the previous step is that the product must be made of components that are as standard as possible, so that they can be easily found.
  The problem is that we don't know any way to express how standard a component is compared to another through a unit of measure. For now, we have opted to express this quantity as the number of suppliers that have the component available and to generalize this definition to more complex systems (like our mechanism) by assigning to them the same number of suppliers having the rarest component. Despite having defined this, we are still not convinced that we have correctly interpreted this part of the analysis for our product. In later stages, we thought that looking at the situation from the opposite side also has some advantages: creating a product that is as non-standard as possible gives us an advantage over competitors, who will have more difficulty replicating our work.
  The question remains open. In any case, the requirements and specifications involved in this latest discussion are not the main points of the project, so we can, for now, continue anyway.

Step 6: relations among requirements and specification

The in-depth relation between the engineering specifications and the customer requirements can be observed in the complete House Of Quality.

Step 7: engineering target

For each engineering specification a target value is defined: the context of our implementation is dominated by the trade secret, thus it is not easy to delineate precise values before simulating the actual system and understanding in depth all the variables involved. Most of the values are just embryonic estimates, based on the little information available on the literature; we will correct these values during the simulation process. In our initial analysis we mainly relied on the publication “An improved active drag reduction system for formula race cars” (Mauro Dimastrogiovanni, Giulio Reina) and on the Moog actuators and valves datasheets (“Micro Hydraulic solutions for F1”), since Moog is a leader company in supplying components for Formula One. All the target values are visible in the House of Quality, we reported those we found here below.

- The opening time of the mechanism must be of about 10ms (the new mechanism proposed by the paper takes about 9ms);
- We did not find any data on the maximum vibration frequency/amplitude that the mechanism must generate, this will be estimated later during the simulation. However, the Moog valve that we analyzed has a maximum value of 50 g for the vibrations that it is able to sustain;
- The force of the actuator (~335 N) was estimated by looking at the data proposed in the paper;
- The drag coefficient of the mechanism must be as small as possible, we proposed a value of 0.05;
- The mean time between failures must be greater than the duration of a race, including a safety factor.
- The time required to do the maintenance must be as small as possible, in order to make sure that the team is able to repair it on time for the next race;
- The maximum operating humidity must be greater than the 100% relative humidity at room temperature, therefore we proposed an absolute humidity of 20 g/m^3;
- The maximum operating temperature was defined by analyzing the Moog datasheets, we opted for 135°C;
- The mechanism must be as light as possible, to permit the fastest opening time without compromising the structural integrity. An estimate of 600g was proposed, but a better value will result after the simulation.

Step 8: relationship among specifications

Some specifications can influence each other in a positive or negative way.

- As the opening time of the mechanism increases, several other specifications decrease and vice versa. The specifications involved are: the residual amplitude of the frequencies (since a slower mechanism doesn’t slam itself open to quickly), the force of the actuator (to have a longer time we need smaller forces) and the energy consumed (because as time gets longer, the forces needed are lower and so is the also energy consumed).
- As the residual amplitude of the vibrations increases, the mean time between failures decreases (since the system is more stressed).
- As the mass of the system increases, also the energy consumed by the actuator, the force of the actuator and the residual vibration amplitude increase due to higher inertias.

Result: our House of Quality

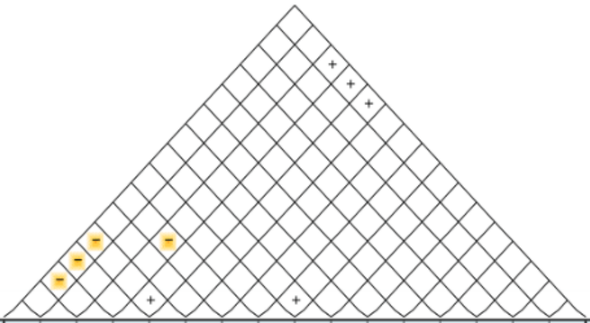
In the following page we report the resulting House of Quality for this first assignment of the project.

QFD: House of Quality
Project: DRS
Revision: 1
Date: 01/05/2022

Correlations	
Positive	+
Negative	−
No Correlation	

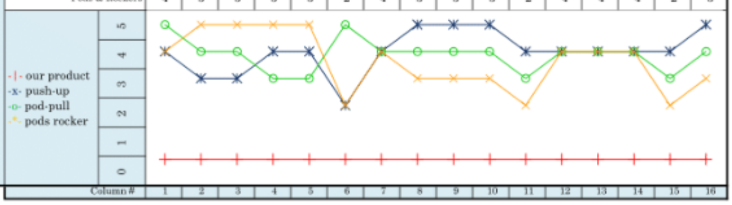
Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	↑
Target	◇
Minimize	↓



		What	Who: Engine Team	Who: Areodynamics Team	Who: Mechanical Team	1 Opening mechanism time	2 Residual vibration frequency of the mechanism	3 Residual amplitude frequency of the mechanism	4 Force of the actuator	5 Energy consumed by the actuator	6 Drag coefficient of the entire mechanism	7 Mean time between failures	8 Steps required to install and disassemble the mechanism	9 Time required to repair the mechanism	10 Suppliers of the rarest component	11 Maximum sustainable load	12 Maximum operating humidity	13 Maximum operating temperature	14 Maximum operating vibration frequency	15 Maximum operating vibration amplitude	16 Mechanism mass	Customer Competitive Assesment (1 = very bad, 5= very good; □ = Push-up type, ◊ = Pod-pull type, ■ = Pods & rockers): 1	2	3	4	5
						↓	↓	↓	◇	↓	↓	↓	↓	↓	↑	◇	◇	◇	◇	◇	↓					
						[ms]	[Hz]	[mm]	[N]	[J]	[1]	[hours]	[#]	[days]	[#]	[N]	[g/m³]	[°C]	[Hz]	[mm]	[g]					
1	FUNCTIONAL PEREFORMANCE	The DRS quickly switches between open and closed positions.	8	14	12	●	○	○	●	●	▽												◊	□	■	
2	FUNCTIONAL PEREFORMANCE	The change of state of the DRS happens without residual vibrations.	8	14	16	●	●	●	●	▽														□ ■	◊	
3	FUNCTIONAL PEREFORMANCE	The force of the actuators of the DRS wins the external forces acting on it.	10	8	25				●	○													◊		□	■
4	FUNCTIONAL PEREFORMANCE	The DRS uses as little energy as possible.	30	5	7	●			●	●													◊		□	■
5	FUNCTIONAL PEREFORMANCE	The DRS disturbs as little as possible the aerodynamics.	9	30	2						●												□ ■			◊
6	RELIABLITY	Failures are not allowed.	10	8	6				○			●	○	○	▽	▽	▽	▽	▽	▽					□ ◊ ■	
7	RELIABLITY	The DRS is capable of working with any environment conditions.	5	4	5										○	○	●	●	○	○					□ ◊ ■	
8	LIFE-CYCLE CONCERNS	The DRS is easy to install and disassemble.	3	2	2								●	○										■	◊	□
9	LIFE-CYCLE CONCERNS	The DRS is easy to maintain and repair.	0	2	2								○	●	▽									■	◊	□
	RESOURCECONCERNS	The DRS is made of standard parts.	2	2	2										●									■	◊	□
11	MANUF. REQU.	The DRS is resistant to high forces and high vibrations acting on the vehicle.	6	6	10											●			●	●			■	◊	□	
12	MANUF. REQU.	The DRS weighs little.	9	5	11	●	▽	○	○	●											●				◊ ■	□

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Target	10 ms			335 N		0.05	6 h	100	1 dd	20		20 g/m³	135 °C			600 g
	Max Relationship	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Mechanical Importance Rating	Engine team	495	105	123	561	461	89	90	57	39	43	79	55	55	79	79	81
Mechanical Importance Rating	Areodynamics team	342	173	183	408	254	284	72	48	48	40	74	44	44	74	74	45
Mechanical Importance Rating	Mechanical team	414	191	213	591	361	30	54	42	42	41	111	51	51	111	111	99
Relative Weight	Engine team	19,9	4,2	4,9	22,5	18,5	3,6	3,6	2,3	1,6	1,7	3,2	2,2	2,2	3,2	3,2	3,3
Relative Weight	Areodynamics team	15,5	7,8	8,3	18,5	11,5	12,9	3,3	2,2	2,2	1,8	3,4	2,0	2,0	3,4	3,4	2,0
Relative Weight	Mechanical team	16,5	7,6	8,5	23,5	14,4	1,2	2,1	1,7	1,7	1,6	4,4	2,0	2,0	4,4	4,4	3,9
Technical Competitive Assesment	Our Product	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
Technical Competitive Assesment	Push-up type	4	3	3	4	4	2	4	5	5	5	4	4	4	4	4	5
Technical Competitive Assesment	Pod-pull type	5	4	4	3	3	5	4	4	4	4	3	4	4	4	3	4
Technical Competitive Assesment	Pods & Rockers	4	5	5	5	5	2	4	3	3	3	2	4	4	4	2	3



Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Sum across specifications
2491
2207
2513

Total sum:
7211