Ducati Chassis Entwicklung –
Simulationen und Experimentelle Untersuchungen

Ducati Chassis Design; Simulations and Experimental Testing

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1. Abstract

Tubular steel trellis frame is one of the distinctive items that characterize Ducati motorcycles. The optimum design of this component is a crucial aspect in the development of the vehicle. In fact the dynamic behaviour of a motorbike is strongly influenced by bending and torsional stiffness of its chassis. Moreover the frame has to withstand the stresses due to the forces transmitted by the rear suspension and by the steering headstock. Last but not least, packaging and stylistic demands has to be satisfied. Ducati chassis design technique incorporates simulations and experimental testing; in this paper it is shown an example of its application to a new project.

2. Introduction

The functions of a motorcycle frame are of two basic types: static and dynamic. In the static sense the frame has to support the weight of the rider or riders, the engine and transmission and the necessary accessories such as fuel and oil tanks. Although less obvious, the frame's dynamic function is critically important. In conjunction with the rest of the rolling chassis (i.e. suspension and wheels) it must provide precise steering, good roadholding, handling and comfort.

For precise steering the frame must resist twisting and bending sufficiently to keep wheels in their proper relationship to one another regardless of the considerable loads imposed by power transmission, bumps, cornering and braking. By proper relationship we mean that the steering axis must remain in the same plane as the rear wheel, so as to maintain the desired steering geometry in all conditions without interference for frame distortion.

Good roadholding means the ability of the machine, through its tyres, to maintain contact with the road. It depends on frame stiffness, tyre type and size, suspension characteristics, weight and its distribution.

Good handling implies that little physical effort should be required for the machine to do our bidding, so avoiding rider fatigue in order to assure comfort. Generally speaking with handling we mean the ease, style and feel with which the motorcycle does our command. It depends on the same parameters as road holding but the requirements are sometimes contradictory and a compromise must be struck, depending on the intended use of the bike.

All these criteria the frame has to fulfil for the expected life of the machine, without deterioration or failure and without the need for undue maintenance [1].

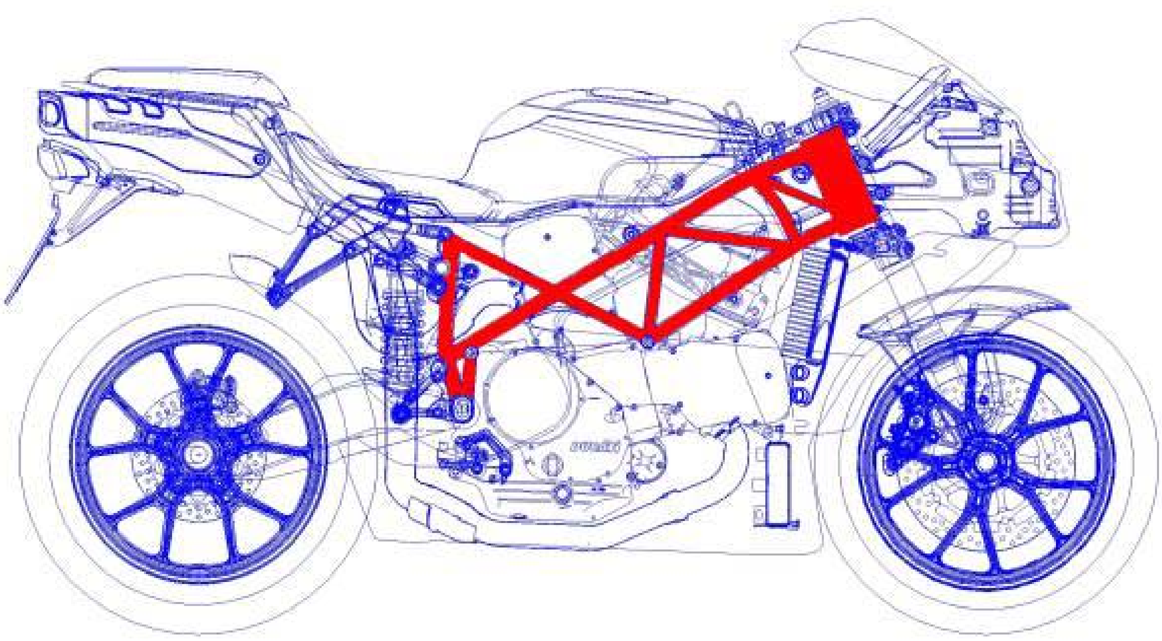

Fig. 1: Ducati triangulated frame.

3. Chassis design criteria

It should be borne in mind that all design is a compromise; the use for which the machine is intended, the materials available and the price the customer is prepared to pay, govern the precise nature of the compromise.
It can be demonstrated that if the components of a chassis are designed to be sufficiently rigid then, provided sound practice is applied to the details, strength will not usually be a problem. Hence, a good guide to the efficiency of a structure is its stiffness/weight ratio. In mass production, however, with common materials, cost is closely related to weight and so a major manufacturer as Ducati might rather measure structural efficiency by the ratio of stiffness to cost.
There are two basic routes to structural efficiency. One is to use many small-diameter straight tubes in a triangulated frame, the other is to use a few large-section tubes and rely on their inherent torsional and bending stiffness. Ducati motorcycles apply a tubular steel trellis frame with the engine being a structural part of the chassis. The engine is rigidly mounted in the chassis and incorporates the swing arm pivot. The rear suspension link pivot is fixed on the frame.

Fig. 2:   Ducati 749 and 999.

Ducati frame is fully triangulated in order to have extremely high structural efficiency. Because of the shape and size of the engine - “L” shaped twin cylinder - it requires a fairly simple texture.

3.1 Chassis material

The selection of the material has to take into account various aspects:

- Young’s Modulus (in order to guarantee the desired stiffness with admissible dimensions);
- Strength properties (static and fatigue);
- Availability of well developed joining techniques;
- Cost of raw material.

The prevailing types of stresses acting on the tubes of a triangulated chassis are tension and compression. The parameter used to compare the stiffness of materials subjected to that type of stress is specific stiffness E/ρ (ratio of Young’s Modulus to density). Some of the most common materials such as steel, aluminium, titanium and magnesium have nearly the same value of stiffness per unit weight, with a small advantage for steel. The aspect that led us to choose steel for our chassis is the strength, which is certainly greater than the one of the other mentioned metals. Using steel tubing will permit thinner walls and relatively small diameters, hence reduced weight.

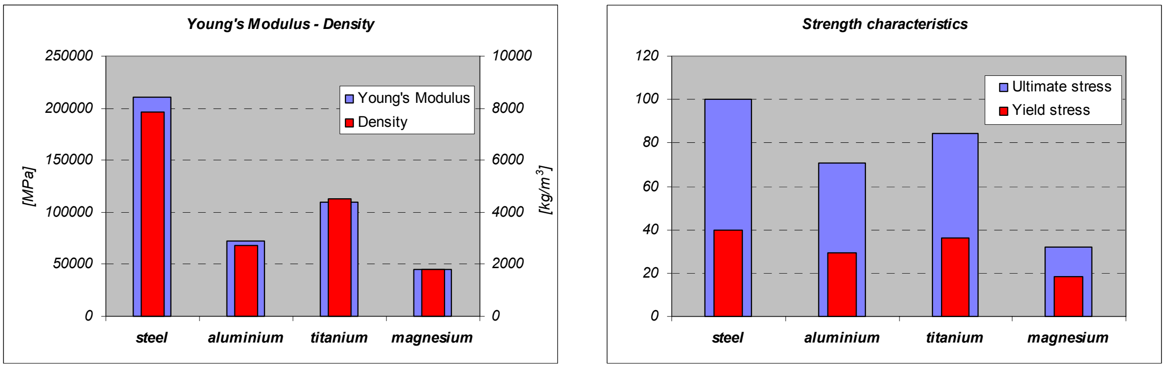

Fig. 3:   Materials characteristics comparison.

Titanium, with its low weight and high strength could be used favourably in a triangulated design. Its chief disadvantages are high costs and the sophisticated welding techniques required.

3.2 Chassis stiffness

Ducati chassis bending and torsional stiffness are measured by means of an experimental test. The frame is fitted with the crankcase and fixed through the swing arm pivot to a surface plate. A rigid bar is used to apply a load to the headstock while two micrometer comparators are placed at the ends of a measuring bar of a given length. The results of the measures are two parameters, torsional stiffness K_t [Nm/°] and the so-called flexo-torsional stiffness K_{ft} [N/mm] that is related to the displacement of the tyre-road point of contact. It is also marked the above mentioned torsional stiffness to weight ratio K_t/P [Nm/°kg].

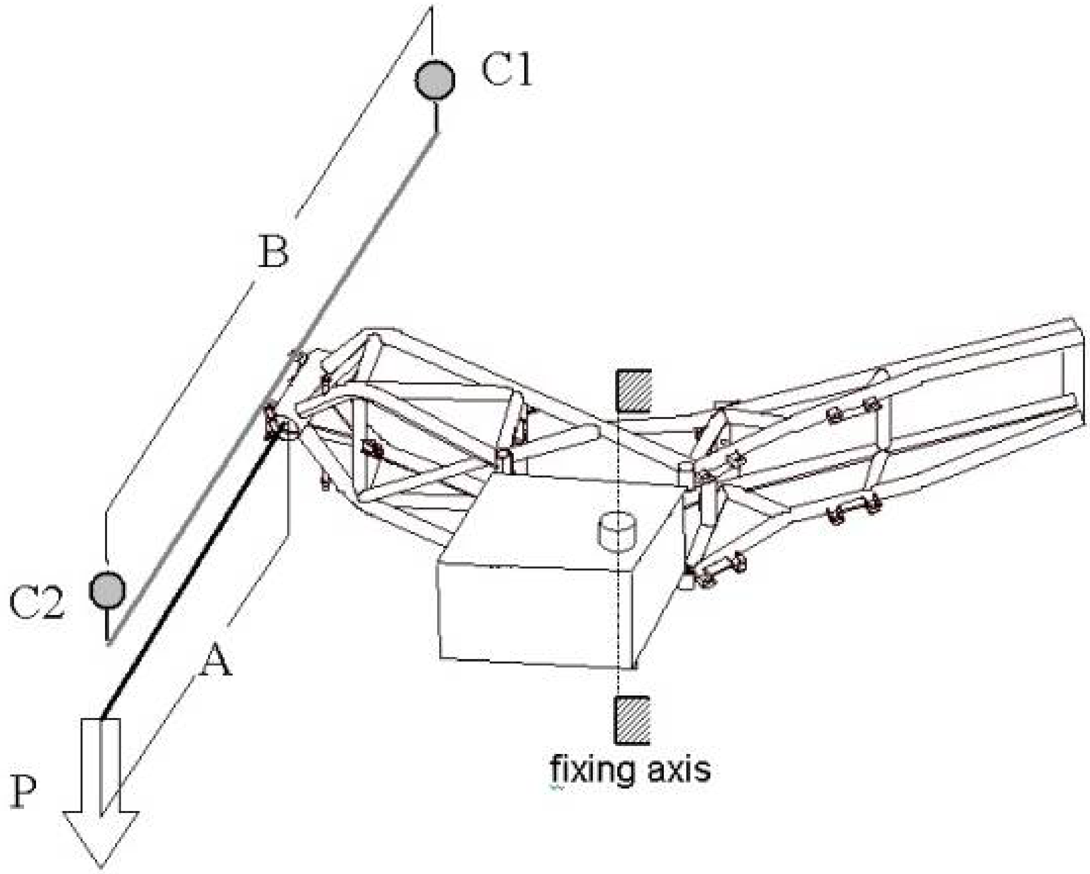

Fig. 4: Chassis bending and torsional stiffness testing procedure.

First step in the design of a new frame is to evaluate bending and torsional stiffness of the initial layout. Therefore a FE calculation that simulates the experimental testing is performed using I-deas. The tubes are modelled using 1D elements with appropriate sections. A simplified beam frame, dimensioned with reference to testing results of known chassis, substitutes the crankcase. Anyway, the engine is typically an order of magnitude stiffer than the chassis. The stiffness of the two components combine roughly as inverses; therefore the engine, when compared to the frame, can be considered as infinitely rigid.

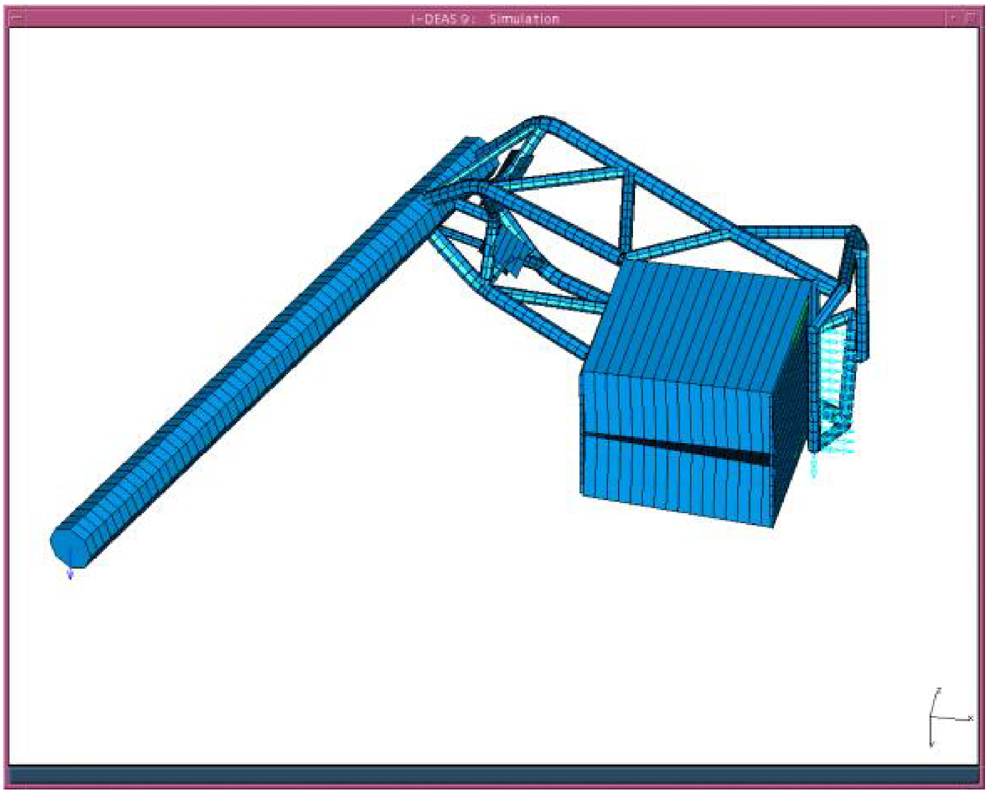

Fig. 5: Chassis bending and torsional stiffness simulation model.

With such a model it is possible to optimise the sections and placements of the tubes in order to maximise the stiffness to weight ratio by means of I-deas Optimisation package.

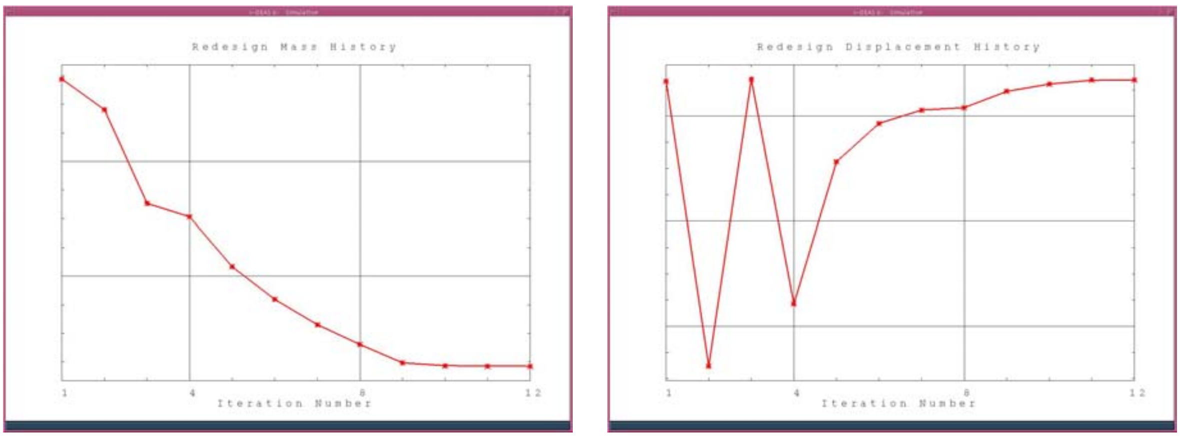

Fig. 6: Example of optimisation results: mass and stiffness.

Such optimisation is done with reference to two load cases – bending and torsional stiffness test and braking – in order to take into account all the type of stresses that act on the frame. Therefore the best solution is the one that allows to obtain the desired stiffness with the minimum mass and without exceeding the material mechanical characteristics.

3.3 Chassis strength

In modern vehicle design, safety requirements are becoming more and more important; this aspect combined with performance and comfort characteristics will determine the quality of the machine. Technically speaking, the safety of a vehicle is tied up to structural reliability of the safety components. Fatigue design process is based on knowing load histories while defining the vehicle mission on one hand and fatigue characteristics of the structural components on the other hand; anyway an experimental approval is always needed therefore it has been necessary to define a testing procedure which was very simple and cheap but dynamically and structurally correct [3].

3.3.1 Frame structural and fatigue analysis

The forces transmitted by the rear suspension and the headstock stress the chassis. The major problem is to estimate or calculate the applied loads and there can be several approaches. One can consider the “worst case” conditions and design for safety under specific maximum loads. These loads can be reasonably well calculated but selection of the conditions is somewhat arbitrary, although past history gives a good guide. If the cases are too severe, weight will almost certainly be excessive, whereas underestimation will result in a fragile structure, intolerant of hard use. Since metal fatigue is the most common cause of failure, in non-extreme circumstances, a study of the high-load conditions gives little indication of the life of a structure in normal service.
On the other hand, it is very difficult to predict the future loading history of a motorcycle. The only solution is to average out the expected life/load records. Such load cycle information can be obtained fitting strain gauges and other transducers on a bike ridden on a variety of road-track conditions, keeping records of the time history of the loading. Given sufficient testing, one can thus build up a picture of the load cycles of a typical machine over its expected lifetime. These data can be directly used having available a very expensive spindle coupled test bench for complete non-constrained motorcycle that is, among other things, of very difficult management. Such systems allow to dynamically simulate the complete vehicle; on the other hand, they are not suitable to rapidly and economically evaluate the principal structural components of the machine because for each test a complete and calibrated vehicle is needed [4].

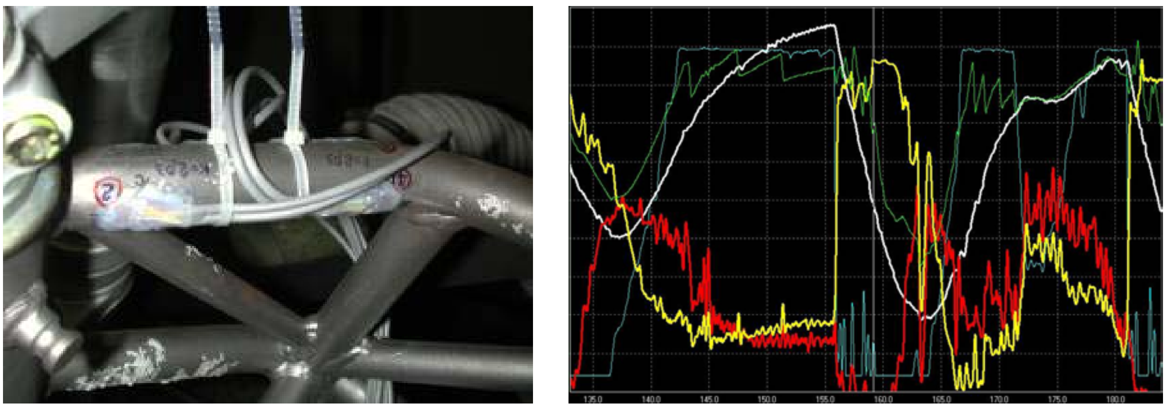

Fig. 7: Example of measured data during road/track testing.

Alternatively, Ducati has chosen to apply a comparative and simplified approach. Durability of both the front and the rear part of a frame are verified using a drum bench. A motorcycle mock-up is fitted with its front/rear wheel on a test bed equipped with a stepped drum rotating at a certain speed; the mock-up is pressed onto the drum with a given force. The other wheel pivot is fixed to the ground. Comparing the load cycles obtained during road-track testing and on the drum bench, it was defined an experimental test procedure that was equivalent to the assumed vehicle mission.

Fig. 8: Fatigue test bed for the front and rear.

Testing parameters such as step height, preload and admissible number of cycles to failure were decided using the correlation with road/track test data. Rotating speed of the drum was chosen to have the best compromise between testing duration and meaningfulness of the results. The target was to obtain the same cumulative damage on road/track and on the test bench.
Main advantages of that test bench are its flexibility, cheapness, speed of testing and repeatability. The drawbacks are the impossibility to apply horizontal forces and variable loads. In fact it is not possible to obtain fatigue stress curves at different load levels because applied forces are essentially dynamics and determined by the interaction among stepped drum, tyre, suspension, frame, constraint and pre-load systems [4].

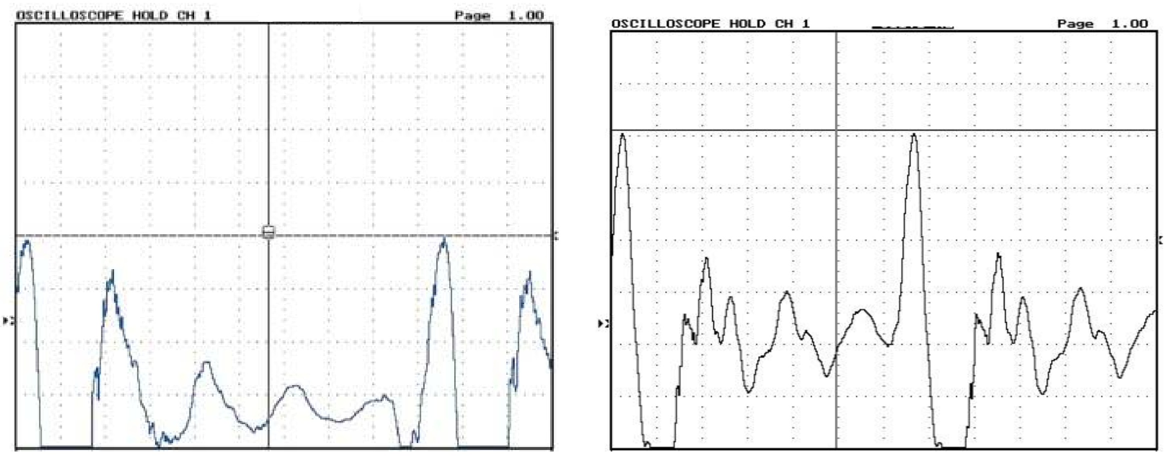

Fig. 9: Typical load cycle on the drum bench for front and rear.

The loads and constraints of the test bench are easily transferred on a FE model. It is then possible to predict the stresses and the estimated life of a structure subjected to that kind of testing. Shell and solid elements are used to build up the FE model in order to have a more detailed description of the geometry of the chassis. All the components not directly involved in the stress investigation (for example: front fork, front wheel spindle, steering head and base, etc.) are simulated using beam elements of appropriate characteristics. Welding is substituted either joining adjacent nodes or using I-deas constraint element, in order to minimize the effects of the geometric discontinuities.

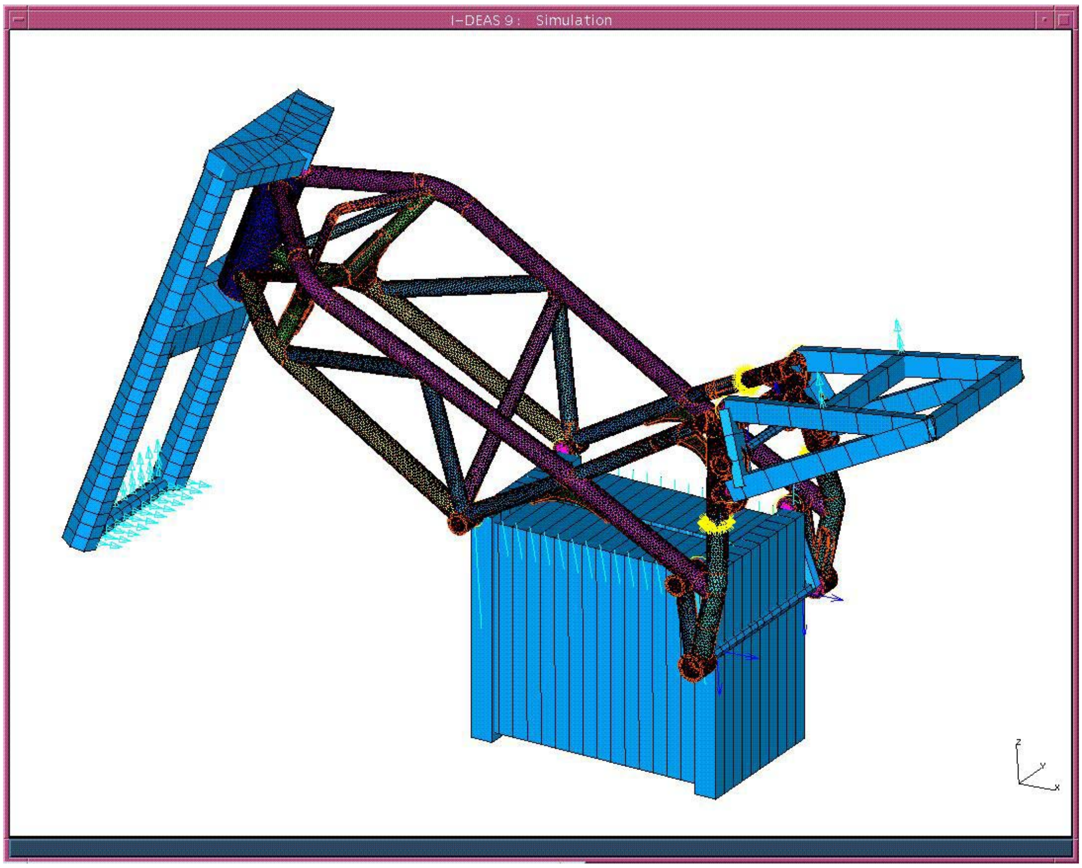

Fig. 10: FE model for stress investigation.

The simulations can show the critical points and strongly reduce the number of test needed to determine the optimum solution.

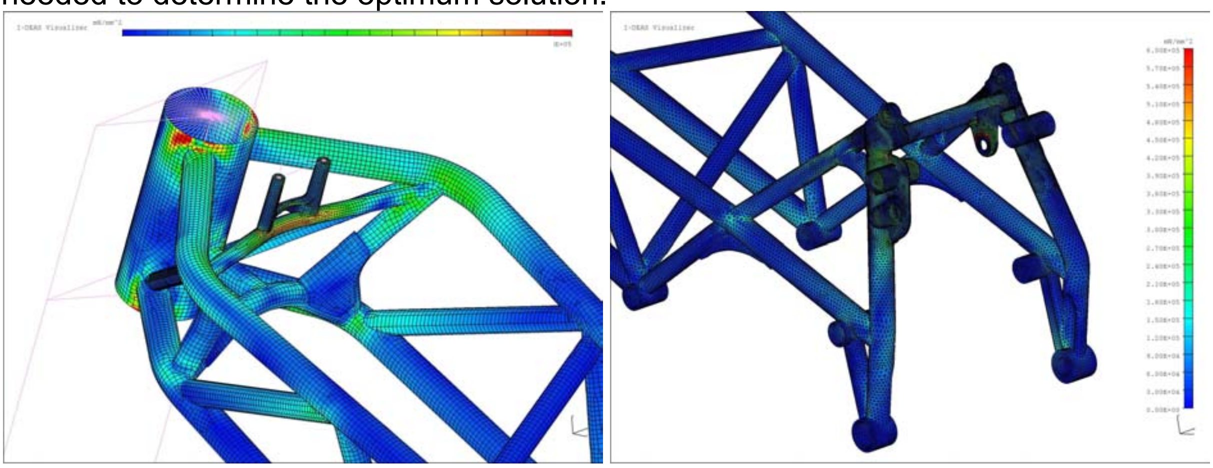

Fig. 11: Stress results of 999 frame, front and rear part.

4. Future developments

In collaboration with the University of Firenze, Ducati is currently developing multi-body cinematic and dynamic models of the motorcycle using ADAMS. The purpose is not to replace the experimental tests using the simulation, but to evaluate more properly the loads that stress the mock-up during the fatigue test, in order to have a better prediction of the life of the structural components. The final purpose is to be able to strongly reduce the number of trials needed to give the release for manufacture. The models we are dealing with are simplified as regards to the tyre model. Moreover, they don't contain yet flexible bodies; next step will be to introduce the FE model of the frame and swing arm.

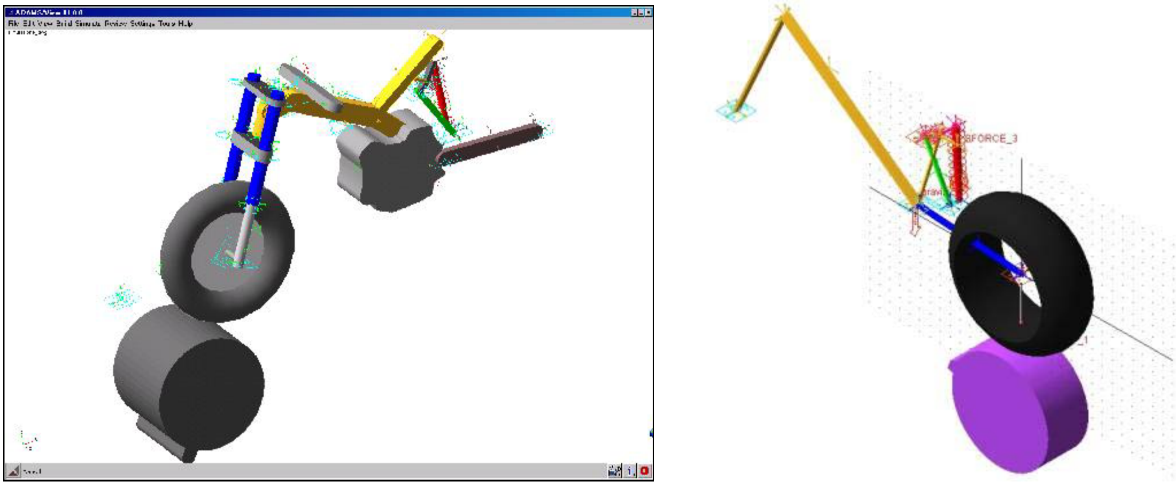

Fig. 12 Multi-body models for the simulation of front and rear tests.

5. Conclusions

Ducati chassis design process takes advantage both of simulation and experimental tools. It was developed in order to give an industrial answer to the task of dimensioning a frame, having in mind the fundamental requirements that such a component is supposed to fulfil. The purpose in defining that process was to find the right balance between analytical prediction and physical confirmation methods. It is currently being updated following the growing of simulation capabilities.

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