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MODULAR APPROACH TO DEVELOPMENT AND SUBSTANTIATION OF HIGHLY DYNAMIC INTEGRATED SYSTEMS

SIMPLE UNITS BUILD A COMPLEX SYSTEM!

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Abstract: This paper discusses the substantiation process of highly dynamic integrated aerospace systems by using simulation tools supported by tests and the interaction between several participants (system integrator versus specialist vendors) to the process with respect to responsibilities and simulation model data.

The paper covers the role of Stork SP Aerospace B.V. as a landing gear and arresting gear specialist in two different aerospace programs and the way the modular approach is integrated in the development and substantiation process. Advantages include extensive knowledge on system behaviour, precise predictability of system capabilities under all conditions, reduction of development risk and the overall 'global-integrated dynamic system-model', used as common platform, does not contain unnecessary details at system level.

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1 INTRODUCTION

One of the principles of systems engineering is the decomposition of the integrated system. This paper covers the way the modular approach is integrated by Stork SP Aerospace B.V. in the design and substantiation process of highly dynamic integrated systems in two different aerospace programs:

- NH90; NHI Industries; Landing Gears
- JSF; Lockheed Martin / Northrop Grumman; Arresting Gears

The substantiation process contains the simulation model building and verification by test on component, sub-system and system level for the required performance envelope.

First some general information on the programs and the role of Stork SP Aerospace is given. Next the substantiation process is described and the way the simulation model data is shared between several participants (system integrator versus specialist vendors).

2 THE NH90 PROGRAM

2.1 General

Stork SP Aerospace is responsible for design, qualification and manufacturing the landing gears of the NH90 helicopter and for the overall landing performance and generated landing loads throughout the helicopter.

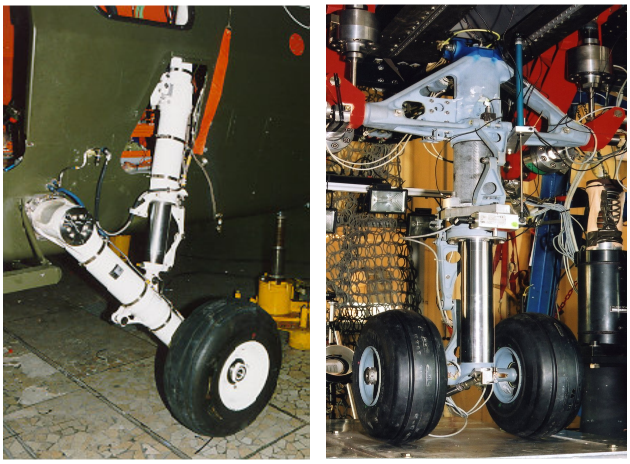

Figure 1: NH90 main (left) and nose (right) landing gear

2.2 Simulation models: System integrator versus specialist vendors

The design of the helicopter takes into account the extreme dynamic loads which are generated during emergency and crash landings. These loads have been fully substantiated, taking into account the dynamics of the landing gear system and fuselage as a whole. In this process detailed landing gear models (validated by tests) are developed by Stork SP Aerospace B.V. The detailed landing gear model completed with a simplified structure representation (Figure 2) is used for landing gear development activities.

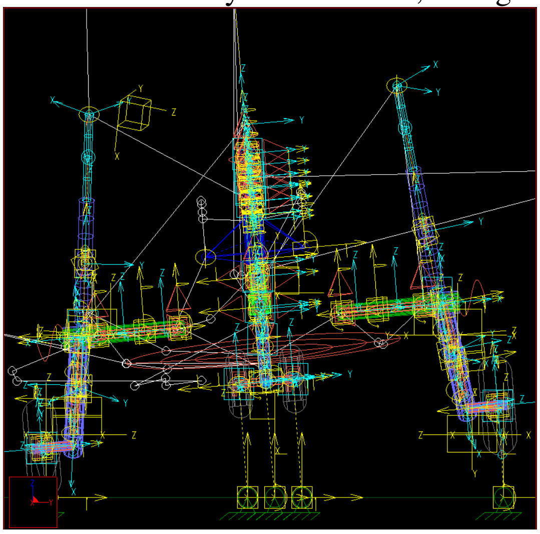

Figure 2: Detailed landing gear model completed with simplified structure

Simplified landing gear characteristics are derived from the detailed models, covering specific operational conditions. In this way there is no need to share detailed model data between specialist vendor and system integrator. The simplified landing gear characteristics are used in the simulation of the system integrator, in combination with a more detailed fuselage model to analyze the coupling between landing gear and structure behaviour (Figure 3).

The substantiation approach uses the 'global-integrated dynamic system-model' as the common platform, where 'local-detailed dynamic-modules' can be inserted to support system development and substantiation at the required levels. The main advantage of this approach is that the overall 'global model' does not contain unnecessary details at system level.

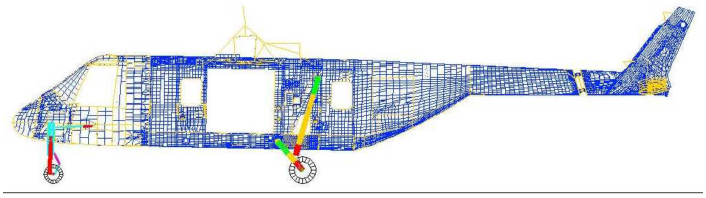

Figure 3: Detailed fuselage model completed with simplified landing gear model

2.3 NH90 Landing Gear concept

One of the requirements for the land based version (TTH) of the NH90 Helicopter (H/C) is airframe crashworthiness derived from MIL-STD-1290A. The total energy to be dissipated during a crash landing must be absorbed by both the Landing Gear (LG) and the H/C structure (mainly the crushable floor) and crew seats. The energy absorption of the crushable floor will take place after the LG has absorbed the major part of its energy. Therefore, in the design of the LG it must be ensured that it will not prevent the crushable floor to continue the energy absorption. Next paragraph describes how the design of the Nose and Main Landing Gear copes with this crashworthiness requirement.

NH90 Nose Landing Gear concept

In Figure 4, a schematic figure of the Nose Landing Gear (NLG) is shown. Based on this figure, the behaviour of the NLG during crash landings will be explained. In figure 4, the following main items can be recognized: Wheels and Tyres, Shock Absorber, Crash valve, Crush Tube, Shear Pin, Inner Cylinder and Break-away Mechanism.

During a normal landing, the pressure in the Shock Absorber (S/A) will rise causing an axial load in the NLG. This load will be reacted by the Shear Pin (S/P) at the top of the Inner Cylinder (I/C). During a crash landing, the axial load causes the S/P to fail. From this moment on the load will be reacted by the Crush Tube (C/T). The C/T starts to crush, absorb energy and act as a load limiter to the H/C structure. During stroking of the C/T, the I/C moves in the upwards direction and slides through the Main Fitting (M/F). After a certain stroke of the I/C, the I/C mechanically activates a Break-away Mechanism which causes the Retract Actuator (R/A) to detach from the M/F. Subsequently, the NLG will rotate backwards into the nose landing gear bay.

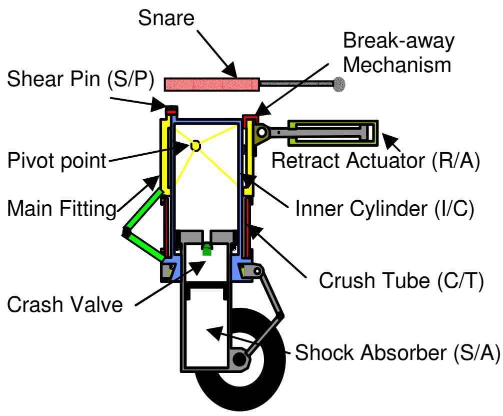

Figure 4: NH90 NLG concept

To control the impact speed of the rotating NLG against the H/C structure, a so-called 'snare'-device has been developed. After the rotation of the NLG, the structure can start to crush and absorb the remaining energy of the H/C.

Note: The vertical ground load is introduced to the NLG with a certain offset or trail causing a moment arm around the NLG pivot point. This will cause the NLG rotation after the detachment of the R/A.

NH90 Main Landing Gear concept

The Main Landing Gear (MLG) concept is presented in Figure 5. The MLG is of the single wheel trailing arm variety. In figure 5, the following main items can be recognized: Shock Strut (Shock Absorber and Retract Actuator), Trailing Arm and Wheel-Brake-Tyre combination. The Shock Absorber and Retract Actuator act as ‘tandem shock absorbers’ during emergency and crash landings. The assembly is attached to the airframe structure through a Pintle Axle. The Trailing Arm rotates around the fixed Pintle Axle. The Shock Absorber is a single acting oleo-pneumatic design. The Shock Absorber Ground Resonance Valve is active during all ground maneuvers and all landings. The Ground Resonance Valve is a two stage pressure / flow sensitive valve. The first stage is used for damping during ground resonance, the second stage during landings.

The Retract Actuator has a dual function. In normal operation it retracts and extends the MLG. During emergency and crash landings the Retract Actuator serves as an additional shock absorber, absorbing part of the kinetic energy and acting as a load limiter to the H/C structure. The Retract Actuator incorporates a claw lock mechanism for locking the gear in extended position. This lock is designed to withstand all loads during normal landings. At loads exceeding the break load the shear pins fail allowing the Retract Actuator to stroke and consequently absorbing additional energy. The crash valve controls the rate of flow, effectively limiting the stroking rate and Shock Strut load.

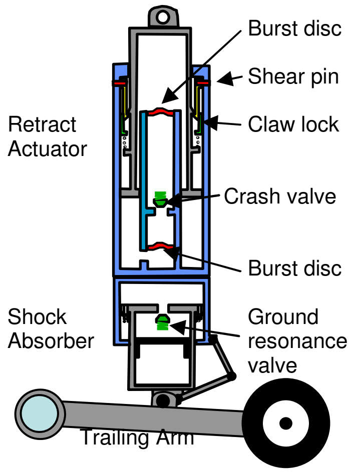

Figure 5: NH90 MLG concept

2.4 Building Block Approach

The Landing Gear crashworthiness substantiation process contains the simulation model building and verification by test on component, sub-system and system level for the required crash envelope (complete range of sinking speeds and helicopter attitudes). Figure 6 shows the substantiation process in a schematic way. The landing gear components are modeled and validated by test results. These models are used to establish sub-systems and system models and to predict subsequent sub-system and system tests which are again validated by tests with these sub-systems and systems. All tests are performed up to equivalent crash velocity of the component or sub-system.

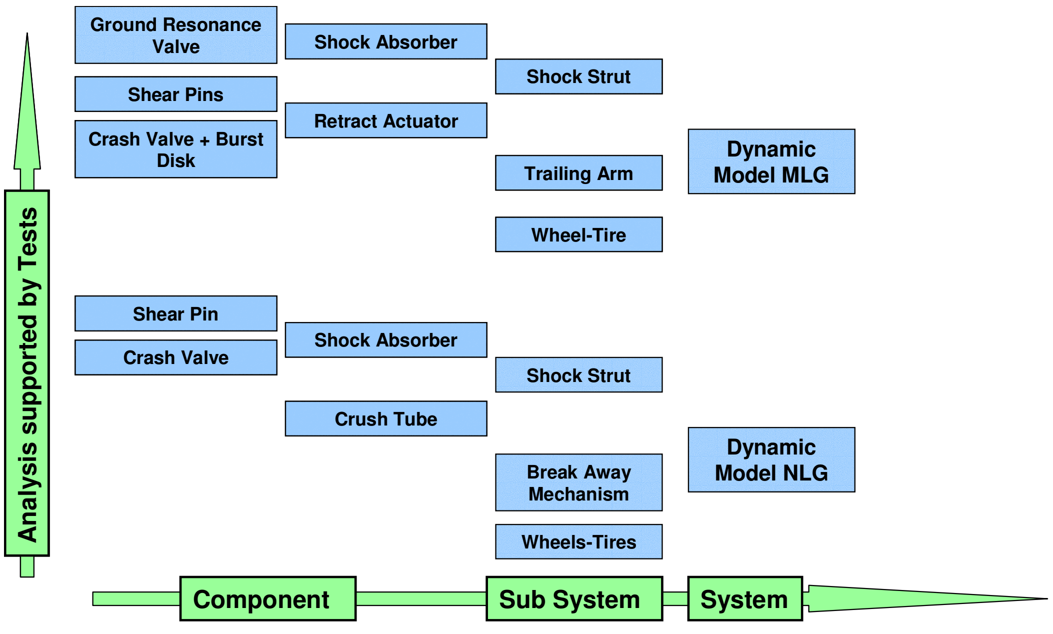

Figure 6: NH90 Landing Gear Building Block Approach

Developing of the dynamic simulation model is an iterative process. During the extensive test program of the different components the dynamic model grows in maturity every time when validation of the different components is successfully finished.

To reach full qualification, both NLG system (in combination with forward fuselage) and MLG system have been successfully drop tested at maximum crash velocity.

The following advantages can be identified by using the Building Block Approach:

- Extensive knowledge on component and sub-system behaviour under all relevant conditions.
- Precise predictability of capabilities under all conditions. Without any risk and high costs, sensitivity studies can be performed using all kind of combinations of initial conditions and / or hardware for the dynamic system. Full size tests for all these conditions are not realistic with respect to risks and costs and they are very time consuming.
- Reduction of development risk

2.5 Simulation Tools

Analysis was performed using Multi-body, Computational Fluid Dynamics and FE analysis techniques, taking non-linear effects into account. Multi-body dynamic analysis was performed to analyze the overall helicopter landing performance and generated landing loads throughout the helicopter. Component flexibility in the dynamic model has been validated by FE stiffness calculations. Additionally Computational Fluid Dynamics analysis of the landing gear pressure relief valves was performed to verify theoretical flow force assumptions used in the Multi-body dynamic helicopter model. The detailed landing gear models, main contributors of the dynamic helicopter model, are validated by drop tests up to crash conditions. Comparison between analysis and test results showed good agreement with deviations less than 10% for the complete performance envelope. Analysis results (both manual and FE analysis) of the landing gear components showed sufficient Margin of Safety and confirmed the structural performance of the landing gears.

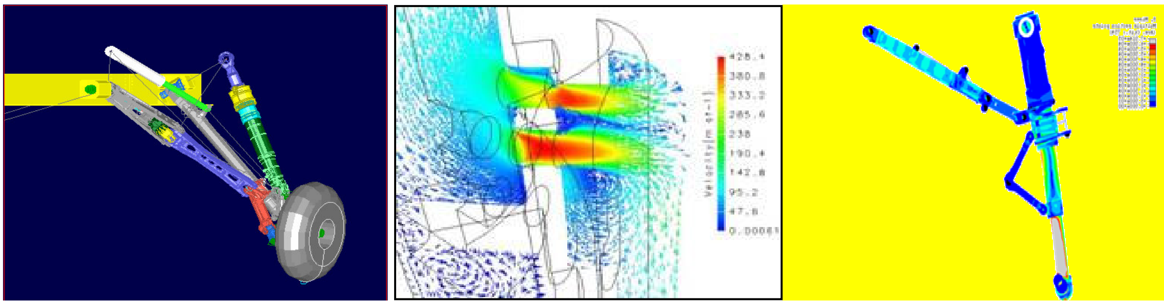

Figure 1: Multi-body, Computational Fluid Dynamics and FE analysis techniques

2.6 Tests

To reach crashworthiness substantiation for the landing gear components, an extensive test program was executed. The component, sub-system and system tests were executed at SP's in-house test facilities, to check performance, stiffness, and strength. Tests performed included mechanical tests to check static strength (e.g. Main Landing Gear Trailing Arm), and drop tests to check the dynamic behaviour of Main and Nose Landing Gear crash system and dynamic tire stiffness. Dedicated drop test instrumentation is used by Stork SP Aerospace B.V. to measure the ground and structure interface loads, internal landing gear pressures, stroking rates of landing gear components and strains at highly loaded locations. The measured signals were used to verify the dynamic behaviour of the landing gear.

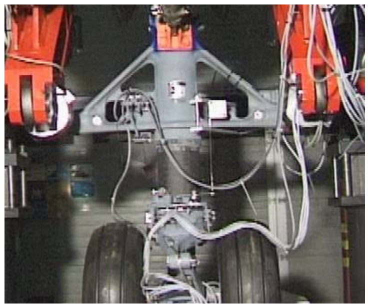

Figure 8: Drop test of NH90 NLG

3 THE JSF PROGRAM

3.1 General

Stork SP Aerospace is responsible for designing and qualification of the arresting gear of the JSF CTOL (Conventional Take-off and Landing) and CV (Carrier Vessel) aircraft. At the moment of writing of the paper, the CTOL arresting gear program is in the Safety of Flight / Full Qualification phase, while the CV arresting gear program is at the end of the Preliminary Design phase.

3.2 CTOL arresting gear design

The JSF CTOL arresting gear is shown in Figure 9. The following main items can be recognized: Actuator / damper combination, hook shank and hook toe.

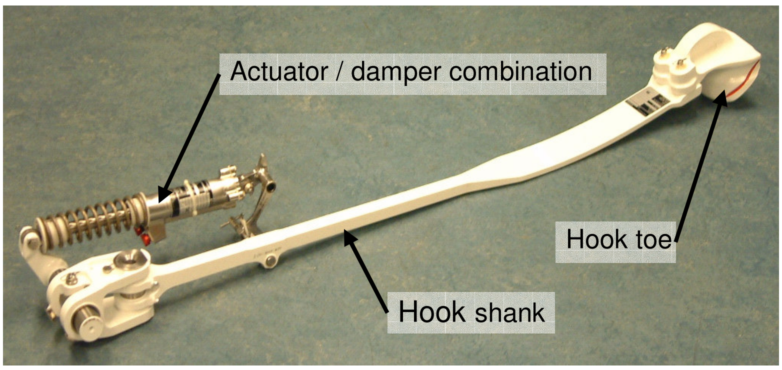

Figure 9: JSF CTOL arresting gear

After deployment of the arresting gear on the runway, the arresting shank is fully extended and remains in contact with the runway. The arresting gear system is able to handle runway discontinuities within specified requirements. Load relief is included in the actuator / damper combination to allow the necessary rapid movement of the hook during cable engagement without overloading the hook assembly and aircraft structure interface.

3.3 Simulation models: System integrator versus specialist vendor

The design of the arresting gear takes into account the extreme dynamic loads which are generated during cable engagement. These loads have been fully substantiated, taking into account the dynamics of the arresting gear system and the cable as a whole. In this process a detailed dynamic arresting gear model is developed by Stork SP Aerospace B.V. The substantiation process contains the simulation model building and verification by test on component, sub-system and system level. Simplified arresting gear characteristics are provided to the system integrator who is responsible for the complete cable engagement simulation at aircraft system level. In this way there is no need to share detailed model data between specialist vendor and system integrator. The substantiation approach uses a ‘global-integrated dynamic system-model’ as the common platform, where ‘local-detailed dynamic-modules’ can be inserted to support system development and substantiation at the required levels. The main advantage of this approach is that the overall ‘global model’ does not contain unnecessary details at system level.

4 CONCLUSION

Integration of the modular approach in the development and substantiation process of highly dynamic integrated systems gives the following advantages: Extensive knowledge on system behaviour, precise predictability of system capabilities under all conditions, reduction of development risk.

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5 REFERENCES

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