

# Complex & Robust

core system integrators on the basis of capability, competency, resources and cost. Goodrich is the F-35 landing gear integrator across all three platforms for the same reasons today.

## Design Specific

Systems include specially-designed and developed non-metallic strut bearings to be used with titanium cylinders on the F-35B STOVL variant, a novel lightweight mechanism to shrink the F-35C CV variant main landing gears for stowage, and an internal fluid-level sensing capability.

When Goodrich started designing the F-35B STOVL landing gear, a standard cantilevered strut capable of being used with titanium cylinders did not exist. A typical cantilevered strut has an upper bearing that slides under high pressure and at high velocity on the internal diameter of the cylinder. Titanium, the material selected for the F-35B strut cylinders, has a propensity to wear and transfer debris to another material, a condition known as galling, resulting in a degradation in service life.

The challenge Goodrich faced was to identify a strut-bearing material that was compatible with the titanium in a high load, high-speed sliding contact environment. Goodrich funded the development and testing of a specially-designed non-metallic bearing compatible with the titanium cylinders.

According to Bill Luce, F-35 Landing Gear Program Manager and Chief Engineer with Goodrich, the design team identified a non-metallic material that would withstand sliding contact with titanium permitting the cylinders to be made from that metal and reducing the overall weight of the landing gear.

Another main design consideration was the restricted space into which the main gear is retracted, which meant the Goodrich designers had to find a way of shortening the gear when it was being stowed. They therefore introduced an additional piston inside the shock strut positioned immediately below the upper bearing on the main piston. A small hydraulic system injects hydraulic fluid between the extra piston and the lower bearing to stroke the main piston. Stroke refers to moving the piston up and down in the cylinder.

"We have a specific volume that we stroke in. Rather than directly connecting the chamber up to the aircraft's hydraulic system, we attach a transfer cylinder to the aircraft's high-pressure hydraulic system which is a relatively low flow rate system," said Bill Luce.

"We use the high pressure to stroke a piston with a mechanical disadvantage, to stroke a larger volume of fluid, at a lower pressure, into the shock strut chamber using the higher pressure fluid from the aircraft with a smaller volume. A series of locks and safety systems ensure that the gear remains shrunk during retraction."

All the landing gears used by the three F-35 variants are fitted with a system to detect levels of fluid inside each strut.

The original design concept for the F-35 landing gear system was to utilize a common structural geometry for both the F-35A CTOL and F-35B STOVL systems with a completely unique system for the F-35C CV. Different materials were to be used in the CTOL and STOVL systems in identically gauged structural components. The CTOL version was to be primarily made of 300M grade steel (a commonly used material in commercial landing gear) and the STOVL variant was to be made primarily of Aermet 100 (a grade for ship-based aircraft) and is the US Navy's choice for high strength steel.

Patented by Carpenter Steel, Aermet 100 has very high strength and slow crack propagation properties, so if a crack develops in the material, the crack will spread slowly with further load applications. By contrast 300M or 4340M grade steel has the same strength quality, but poor crack propagation. This gives more opportunities to discover cracks in the structure before a catastrophic failure occurs.

Each type of F-35 landing gear has a Goodrich-proprietary system integrated within the aircraft's maintenance system to help the maintainer assess the level of the gas and oil in each shock strut during servicing.



Goodrich Corporation's landing gear business has introduced many technological breakthroughs in the aerospace industry making it one of the world's premier suppliers of landing gear. Goodrich pioneered the use of a gas-oil strut, introduced high-strength steel and advanced titanium alloys, unique fracture-resilient material for carrier operations and 'smart' health management systems.

Many of these technologies and others were adopted to meet the performance requirements of the F-35 Lightning II programme. The company received multiple design specifications to meet the aircraft's requirements for applied loads, stroke, landing gear length and operating environment.

From the inception of the design requirements through the design and testing phases, Goodrich integrated the design and performance requirements for the landing gear strut, sub-systems design, and test requirements, including rolling stock (wheels, tyres, and brakes), nose wheel steering, and electrical/hydraulic systems from the prime contractor Lockheed Martin. At the beginning of the F-35 programme, Lockheed Martin subcontracted various sub-systems to companies as



ABOVE: The CV nose gear staged shock strut carries a very complex mechanism to position the launch bar on to the catapult. KEY - MARK AYTON  
OPPOSITE: Landing gears for the F-35C CV variant are unique and differ to the F-35A and F-35B systems to withstand the extreme high energy landings typical of naval aircraft operating from an aircraft carrier. LOCKHEED MARTIN



MARK AYTON EXPLAINS THE HIGHLY COMPLEX LANDING GEAR SYSTEMS USED ON THE F-35

## CATS AND TRAPS

Landing gears for the F-35C CV variant have to be able to withstand extreme high energy landings typical of naval aircraft operating from an aircraft carrier as well as the nose tow launch. Both the F-35C nose and main gears are made primarily of Aermet 100 steel.

The nose gear of the CV variant is a dual stage gas over oil cantilever strut with a staged air curve that provides a source of high energy, which helps the aircraft to achieve adequate angle of attack when released from the catapult during take-off from the aircraft carrier.

The CV nose gear carries a complex mechanism which positions the launch bar in readiness for various stages of operation during the launch of the aircraft off the carrier. The mechanism is driven by a power unit comprising a number of powerful springs and a small internal actuator.

There are two reasons for having a staged shock strut for the nose gear on the F-35C CV variant. One is to provide a stable platform for loading and unloading weapons and for engaging the catapult equipment. The second is to store energy gained from the compression of the strut under the high pressure effect of the catapult. When the catapult lets go of the launch bar, the energy is released, providing a rotation that helps achieve the angle of attack necessary to get off the deck.

Similarly when the aircraft hits the deck on landing the strut is compressed and energy is stored to help rotate the aeroplane and get it back off the deck if the arrestor cables are missed and a 'go-around' or 'bolter' is required. Bolter is the term used when the aircraft's tail hook misses the arrestor cables on the carrier deck forcing the pilot to go around for another landing.

The CV nose gear also has a locking drag brace and a launch bar that acts to transmit the high launch load from the catapult equipment to the airframe. A separate retract actuator provides the force to retract the gear into the wheel well. One end of the retract actuator is attached to the landing gear structure and the upper end to the airframe structure.

Fitted to the aft of the strut is a power unit housing an actuator that hydraulically lowers the launch bar to the deck to engage the catapult. When the launch bar hits the deck a second set of springs inside the power unit provide lighter power so that the launch bar can move up and down to engage the shuttle, without jamming or binding, or badly wearing the deck or the launch bar. Large powerful springs are able to pull the launch bar back up to an intermediate position when the hydraulic power is released.

The power unit also has a linkage that operates off the motion of the drag brace during retraction to position the launch bar in a stowed position (virtually parallel to the strut) when the gear is retracted. During the retraction process the launch bar moves upwards but also rotates around the strut to reduce the actual footprint within the stowage bay.

The torque arms that typically maintain alignment between the strut piston and the steering unit are on the aft of the strut as well, and have a fitting at the apex that engages the repeatable release holdback bar (RRHB) of the ship. This bar holds the aircraft back during engine runs and while the load builds during the start of a catapult sequence. Once the load reaches an adequate level, the RRHB releases the torque arm



An F-35A CTOL nose gear in a test jig. GOODRICH  
BELOW: Main gears of the F-35B STOVL variant are dual stage gas over oil cantilever struts manufactured primarily from Aermet 100 steel. LOCKHEED MARTIN

fitting, allowing the aircraft to be catapulted to flight. In comparison to the F-35A CTOL and the F-35B STOVL, the nose gear of the F-35C CV has a dual wheel/tyre arrangement to straddle the catapult equipment and to adequately react to the loads. Nose wheels are the same as those used on the other variants but the tyre was developed specifically for the F-35C.

Like the CTOL and STOVL variants, the CV main gear is a dual stage gas over oil cantilever strut with staged air curves that provide a stable platform for loading and unloading weapons and hold stored energy to assist in getting airborne in the case of a 'bolter' during carrier operations.

The main gears have a retract actuator between the strut and the airframe, providing the force to retract the gear into the wheel well. Each also has a drag brace with locking linkage and locking actuator with backup springs to react force and aft ground loads. The F-35C's drag braces attach to a collar on the strut and a pivot pin in the aircraft that roll around the strut centreline during retraction to minimize the amount of space in the bay when retracted.

Featuring a long main strut the F-35C's main gear has a shrink mechanism to shorten the strut prior to retraction so it will fit within the available space. The Goodrich-proprietary shrink mechanism utilizes a novel transfer cylinder to convert high pressure and low flow aircraft hydraulics into a low pressure and high flow shock shrink hydraulics.

Unlike the nose gear, the CV main gear system utilizes the same main wheel and brake as the F-35A CTOL. All tyres used on the F-35C CV variant are significantly more robust than the CTOL and STOVL variants, because of the high energy landings on top of arrestor cables.

