The number of active 737-300/-400/-500s has declined by about 1,000 units over the past eight years. The remaining aircraft in service are 14-28 years old. With the surplus of used and time-continued engines on the market, these can be maintained at low cost.

The maintenance management of old CFM56-3 engines

The 737 Classic fleet is still operated in large numbers, with an active fleet of about 900 aircraft. Since 2005, when there were almost 1,900 active 737 Classics, an average of 125 have been retired from service every year, with as many as 200 being retired in some years. The rest of the fleet is 14-28 years old. Many of these aircraft are likely to be retired over the next five to 10 years, although freighter aircraft will operate for longer. Having a mature aircraft like the 737 Classic in the fleet, involves managing its CFM56-3 engines to achieve the lowest possible maintenance costs for the last few years of operation.

Maintenance management

Management of engine maintenance requires a long-term strategy in the early- and mid-life periods to achieve the lowest possible costs per engine flight hour (EFH). The maintenance reserves are divided equally between the cost of turbomachinery parts that are maintained on an on-condition basis, and the life-limited parts (LLPs) of discs and shafts, which have fixed lives.

A shop visit to repair or replace turbomachinery parts and restore engine performance can cost as much as $2.0 million. The cost of LLP replacement has to be amortised over their lives of 20,000-30,000 engine flight cycles (EFC), equal to 8-12 years of operation. The lowest costs per EFH or EFC are therefore only achieved if the longest possible intervals between shop visit removals are reached, so airlines need to strike a balance between the workscope of an engine shop visit, the intervals between shop visits, and matching the intervals as closely as possible to LLP lives.

Once engines are mature or in the latter phase of their lives, they can be managed to avoid certain maintenance costs while continuing to operate for a few more years. The on-going costs of maintaining engines in their early- or mid-life period can be reduced with several management methods.

The first method involves not replacing LLPs in the engine when they reach life limits, so that the operator can avoid paying reserves to replace the LLPs installed in a module. This means that this will have to be the last set of LLPs used. Once the number of remaining EFCs for the LLPs in these modules approaches zero, the module will have to be discarded if reserves have not been paid for LLP replacement. The life limits of LLPs are 20,000EFC in the high pressure compressor (HPC) and high pressure turbine (HPT) modules, 25,000 in the low pressure turbine (LPT) module, and 30,000EFC in the fan and low pressure compressor (LPC) modules.

Discarding modules because LLPs will not be replaced also means that the operator will have to swap expired modules for time-continued ones with some time on-wing remaining, both in respect of LLPs, and the condition of the turbomachinery and the remaining exhaust gas temperature (EGT) margin.

Using time-continued modules can only be considered if there is a plentiful supply on the used market. A high enough supply of modules in good maintenance condition will reduce value to a level that makes it more economic to buy a time-continued module than to replace LLPs and put the existing module through a shop visit.

A more moderate maintenance management policy, where modules are put through lighter shop visits and LLPs are replaced with time-continued parts, can be adopted if time-continued modules are in short supply, or if engines still have to be operated for an extended period.

CFM56-3 family

The CFM56-3 is a conventional two-shaft turbofan that has four thrust ratings of 18,000lbs, 20,000lbs, 22,000lbs and 23,500lbs. Engines rated at 23,500lbs are classed as category C engines, those rated at 22,000lbs and 20,000lbs are classed as category B, while those rated at 18,500lbs are category A.

The -3 series has a 60-inch diameter fan, a three-stage LPC, a nine-stage HPC, a single-stage HPT, and a four-stage LPT. The CFM56-3 has bypass ratios of 4.8:1 for the highest thrust ratings, and up to 5.1:1 for the lowest thrust ratings.

There are three main variants, the -3B1, -3B2 and the -3C1, which share the same turbomachinery configuration. There are, however, different turbomachinery parts and build standards.

The -3C1 variants were built from 1986, and are capable of all four thrust ratings because they have the highest standard of material in them. Thrust ratings are changed through the dataplate in the full authority engine control (FADEC) unit.

The -3B2 engines have three ratings of 22,000-18,500lbs, while the -3B1 engines have ratings of 20,000lbs and 18,500lbs.

The largest 737-400 can be powered

All engines manufactured with a prefix of 724, 725, 856 and 857 have -3C1 material and build standard. This means these engines are capable of all four thrust ratings between 18,500lbs and 23,500lbs. This gives operators flexibility in swapping engines and modules.

with the -3C1, rated at 23,500lbs or 22,000lbs, and the -3B2, rated at 22,000lbs.

The 737-300 can be equipped with the -3C1, rated at 22,000lbs, the -3B2, rated at 22,000lbs or 20,000lbs, and the -3B1, rated at 20,000lbs.

The 737-500 can be equipped with the -3C1, rated at 20,000lbs or 18,500lbs, and with the -3B1, rated at 18,500lbs.

"The issue of variant and thrust variants is slightly more complex," says Kevin Hill, director of technical operations for engine trading at AerSale. "All CFM56-3 engines manufactured with a prefix of 724 and 725, which was from 1989, have the -3C1 material and build standard in them, and so are capable of thrusts up to 23,500lbs, even if they are actually designated as a -31 a or a -3B2. Also, engines with prefixes of 856 and 857 have the -3C1 hardware."

The common hardware standards of most engines mean that airlines have the flexibility to swap engines between aircraft variants.

There are 610 active aircraft with -3C1 engines, and another 186 parked aircraft. There are 149 active aircraft with -3B2 engines, and another 70 parked aircraft with the -3B2.

There are also 145 active aircraft and 107 parked aircraft with -3B1 engines.

This totals 904 active aircraft, and 363 parked aircraft. A total of 1,808 engines are required to operate the 904 active aircraft, while up to 726 engines are installed on the parked fleet.

There are also several hundred engines from 721 aircraft that have been retired, as well as those that served as spare engines for the 1,988 737 Classics that were originally built.

"We know that more than 25% of the fleet is parked, and that 300-400 engines have been retired annually in recent years," says Dan Watson, chief commercial offer at MTU Maintenance Canada. "We estimate that 2,500 engines are left in operation, but the number is declining all the time. The fleet can be divided into two categories: stable fleets with airlines, like Southwest, that are operating 737 Classics with a long-term view; and airlines operating the 737 Classic as a low-risk option, with a short-term view of the aircraft."

LLPs

The CFM56-3 has 19 LLPs, divided into three parts in the fan/LPC, five parts in the HPC, four parts in the HPT, and seven parts in the LPT. The list price for a full shipset of19 LLPs is $2.34 million.

The target life limits set out by CFMI were uniform lives of 30,000EFC for the three parts in the fan/LPC, 20,000EFC for the nine parts in the HPC/HPT, and 25,000EFC for the seven in the LPT.

The actual permitted lives, however, vary with thrust rating. There are several part numbers available for each LLP, and some of these have restricted lives.

The three parts in the fan/LPC modules have a list price of $460,000, and are certified at 30,000EFC for engines with a category A thrust rating, the lowest thrust rating of 18,500lbs. Some P/Ns for the fan disk have restricted lives of 20,000-25,100EFC for class B engines, and some P/Ns with restricted lives of 16,300-24,800EFC for class C engines at the highest thrust rating of 23,500lbs. All P/Ns for the other two LLPs in the LPC have full lives of 30,000EFC.

The actual original life limits of LLPs installed in these modules will therefore vary. Some operators will have engines that reach limits as early as 16,300EFC for category C engines. This will force the removal and complete disassembly of the module, and consequently a full shop visit, for this module.

The five parts in the HPC have a list price of $627,000. The target life of these parts is 20,000EFC. There are two P/Ns for category C engines that have lives of 16,000EFC and 18,600EFC. Some P/Ns have even greater life restrictions of 13,300EFC, 17,000EFC and 18,000EFC for category B engines. Some P/Ns have lives as short as 12,000EFC in category C engines, and the longest life limit for some parts in this module is 15,000EFC. Category C engines will therefore be forced into a shop visit by this life limit.

The four parts in the HPT also have a target life of 20,000EFC, and have a list price of $514,000. Even for category C engines, two of three P/Ns available for the HPT disk have lives of 11,400EFC and 16,300EFC. Category B and C engines also have the same life limit for the same P/N. Although there are HPT P/Ns with longer life limits, the HPT front air seal also has short limits of 15,800EFC for category B, and 15,100EFC for category C engines. Overall, the HPT will be forced into a shop visit after fewer than 16,000EFC in the case of category B and C engines.

The seven parts in the LPT have a target life of 25,000EFC, and a list price of $731,000. All seven parts for category A engines have P/Ns with a limit of 25,000EFC, but there are some P/Ns with shorter limits of 12,100-20,000EFC. The life limits of the same P/Ns are as short as 9,300EFC and 11,400EFC in category B engines, and even shorter at 5,700EFC and 7,900EFC in category C engines.

The implications of some P/Ns having life limits shorter than the target lives, and more importantly there being parts in each module with a mixture of life limits, are that modules will first be forced off-wing when the LLPs with the shortest lives are close to zero. This will leave the LLPs still on the engine with 'stub' lives. That is, a remaining life of a relatively small number of EFCs.

These LLPs will have uneven stub lives. Operators need to decide whether: it is economic to replace the modules

There is now a large supply of time-continued engines. This means airlines have a good chance of being able to acquire modules with some life-limited parts that have several thousand EFCs of remaining life. Airlines can this avoid paying full reserves of LLPs for the last few years of operational life.

with a time-continued module that is in a better maintenance condition and has LLPs with longer lives; to put the module through a relatively light shop visit and replace those LLPs with the shortest lives; or put the module through a full shop visit and replace some of the LLPs, either with time-continued parts from the used market or with new parts.

Removal intervals

The CFM56-3 is typically operated at 1.1-1.5 EFH per EFC, so its removal intervals are driven mainly by loss of EGT margin and operating performance. Removal intervals are therefore more driven by accumulated EFC on-wing.

All CFM56-3 engines are at maintenance maturity, so EGT margins of new engines are no longer relevant. The highest EGT margins of engines following a shop visit or overhaul are about 90 degrees centigrade for an engine rated at 18,500lbs, and 80 degrees for an engine rated at 20,000lbs. They are then much lower at 40 degrees for engines rated at 22,000lbs, and 30 degrees for engines rated at 23,500lbs.

These EGT margins will not necessarily be reached with engines being operated, especially if engines are not being put through full shop-visit workscopes to achieve the longest possible removal intervals subsequent to the shop-visit input. “The actual EGT margins are likely to be 20-30 degrees for a -3C1 post-shop visit and overhaul,” says Watson. “The -3C1 engines have fast deterioration on-wing, and consequently have short removal intervals. These are likely to be 5,000-8,000EFC.

“Category B engines at 22,000lbs thrust will have EGT margins similar to, or a little higher than, category C engines, and can achieve similar intervals of 6,000-8,000EFC,” continues Watson.

The likely removal intervals of these two categories of higher-rated engines are only half, one-third or one-quarter of the life limits of the LLPs. This means that several shop visits are possible prior to the expiry of most LLPs. Moreover, the intervals are similar to half or one-third of the life of the LLPs with short lives. A removal forced by the expiry of an LLP with a short life could therefore coincide closely with a shop visit.

There were some category C and B engines that were modified with CFMI’s Tech Insertion upgrade programme. This kit was installed in engines during a shop visit, and upgraded its turbomachinery, in particular the HPT blades. This increased EGT margin by 15-20 degrees, and so increased the removal interval by 3,500-4,000EFC. It also resulted in a fuel burn reduction of 1.6-1.8%. Category C and B engines with this upgrade could therefore achieve removal intervals of 9,500-12,000EFC. Only one main shop visit would be needed before a full HP module overhaul and LLP replacement and the next removal.

Joana Palmeiro, powerplant engineer for the CFM56-3 at TAP Maintenance & Engineering, explains that the lowest-rated category A engines at 20,000lbs and 18,500lbs will have EGT margins of about 70 degrees centigrade. This should allow them to achieve longer intervals of 15,000EFC or more.

Unlike category C and B engines, the removal intervals that are possible with the EGT margins of lower-rated engines are more likely to be interrupted by the expiry of LLPs with short lives.

The main removal causes for engines can be the expiry of LLPs with short or stub lives. “In most cases, the main cause of a scheduled removal for a -3C1 or a category A engine is EGT margin erosion,” says Palmeiro.

With longer intervals for engines possible because of higher EGT margins for category B engines, there are other factors that drive engine removals. “These include degradation of the LPT first stage nozzle guide vane (NGV), and then EGT margin erosion,” says Hill. “The first stage NGV in the LPT is also a problem in -3B1 or category C engines.

Several airworthiness directives (ADs) and service bulletins (SBs) have affected the CFM56-3 since it entered service in 1985. Some of these ADs and SBs did force the early removal of engines due to the need for particular inspections, but in recent years this has not been the case. Nevertheless a few issues have affected the size and cost of engine shop-visit workscopes. “The first is SB 72-0848, which involves applying a coating on the first-stage LPT nozzles and second-stage LPT blades during a shop visit,” says Palmeiro. “The SB is optional, but applying these coatings is recommended in most cases. Another issue is that CFMI recently introduced a recommendation to the engine shop manual to scrap LPT stage 1 NGVs that have had more than three repairs code X.”

Lease return conditions

Managing CFM56-3s to avoid the high cost of replacing LLPs and full workscopes on individual modules is a complex process. Engines have to be considered carefully on a case-by-case basis.

“An operator has to put its engines into two categories,” says Hill. “The first is the engines it owns, and is free to do what it likes with in terms of LLP status and maintenance. The second is the engines that are owned by lessors, either engines installed on the aircraft, or supplied as spare units on medium- or long-term leases. An operator has to manage leased engines carefully, since lessors have return conditions that stipulate particular maintenance status and remaining LLP lives. This will affect shop-visit workscopes. Operators frequently build engines or modules with LLPs with mismatching lives.

“The return conditions that lessors

Airlines have to carefully consider mixing modules of their own engines with time-continued modules acquired on the aftermarket. One important issue is to match modules with LLPs that have the right number of remaining lives.

stipulate in their lease contracts typically call for a minimum of 3,000EFC remaining life in the LLPs and probable on-wing life until another shop visit is required," continues Hill.

The potential market interest for old engines is limited, so it has become easier to negotiate the return conditions with lessors. "Airlines will have paid maintenance reserves to lessors during the lease to cover the cost of maintenance when it is required," says Hill. "Lessors sometimes prefer to keep these reserves, rather than put the engine through a shop visit, because there is generally a large supply of time-continued and serviceable engines on the used market, and the chance of remarketing old engines in these circumstances is small. The situation can change when all the better-quality time-continued engines are used up, as their market values increase, and it becomes economic again to put engines through a shop visit."

Hill gives the example of a low-rated, old -3B1 engine. "A lessor may accept the engine in an as-is condition, keep the maintenance reserves, and tear down the engine and sell what parts it can on the used market. It is worth putting a mid-1990s -3C1 engine through a shop visit, or warehousing it until demand increases and values improve," concludes Hill.

Low-cost engine management

As described, the cost of managing the engines for the few remaining years of life can be minimised by avoiding the replacement of LLPs and full engine workscopes.

This strategy has to be considered carefully, however, because it is highly dependent on an adequate supply of modules with turbomachinery in the right maintenance status and with LLPs that have enough life for the anticipated remaining period of operation. The number of remaining EFCs to meet lease-return conditions after the period of operation also has to be considered. "It is not that easy to find modules with the appropriate remaining life and hardware at the right price," says Watson.

This problem starts with the way an engine is managed in its early and mid-life period.

Parts in the HPC and HPT modules will have been replaced at intervals that are likely to be after a total time of 15,000-18,000EFC, given the actual life of some P/Ns in these two modules.

LLPs in the LPT will have been removed at a subsequent shop visit, and parts in the fan and LPC LLPs will have been replaced at a further shop visit.

The overall result is that engines in the latter part of their lives will have had HPC and HPT LLPs replaced several years before the parts in the LPT and fan/LPC were replaced. Engines will therefore have LLPs that have accumulated a different number of EFCs since installation. This will make it difficult to match modules by using time-continued modules or LLPs with remaining life acquired from the used market.

The LLPs in the LPT and fan/LPC, however, should only need to be replaced once in the engine's operational life if all parts had been at the target lives of 25,000EFC and 30,000EFC in these two modules. If engines are to operate at a relatively high number of cycles per year, then it is possible that LLPs in the low pressure (LP) modules may need to be replaced a second time. The restricted life of some P/Ns in these modules would also force a replacement for a second time in an engine's operational life. The expiry of LLPs in the LP modules for the second time on older engines, and for the first time in younger engines, is an opportunity to save costs by acquiring time-continued modules or just a few LLPs.

The LLPs in the high pressure (HP) modules will need to be replaced twice in the engine's operational life, if the engine is to operate beyond 15-18 years of age.

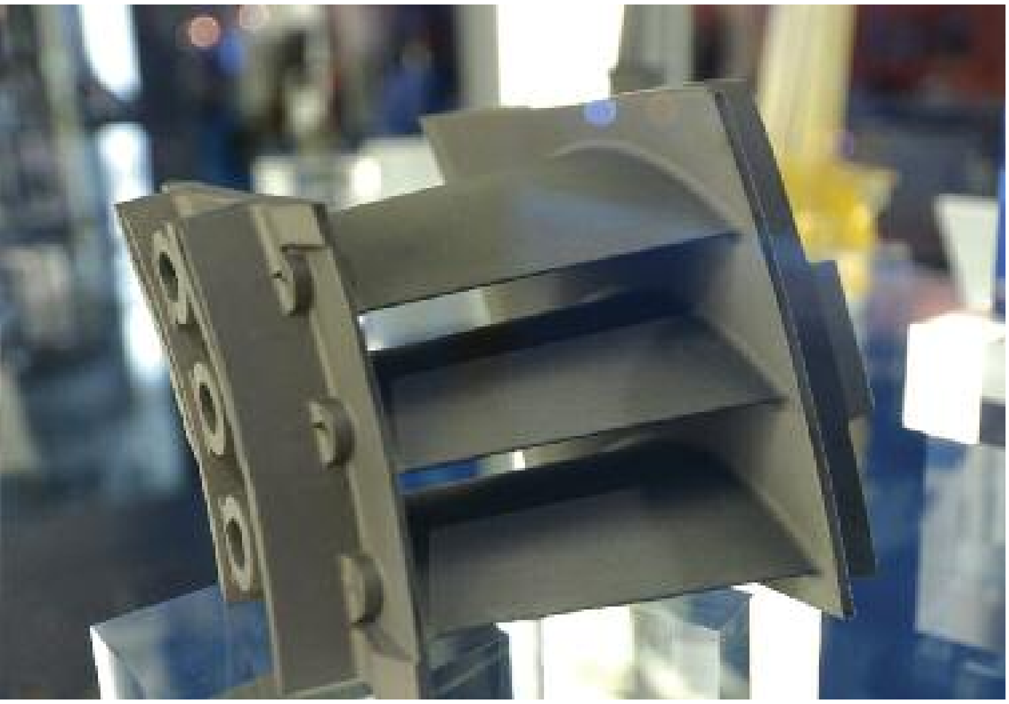
"When aircraft are older and retirement is just a few years away, there is no point building it in the shop for five years if you are only going to operate it for another two or three years," advises Chris Pelly, senior vice president of commercial at Total Engine Support. "There are a few occasions where a new LLP has to be bought to support the build goal. Given the number of engines that have been torn down over recent years there should be enough LLPs on the used market to support most builds."

It is generally accepted that in the case of CFM56-3s it is possible to perform module change, as opposed to full restoration shop visits.

"When time-continued modules are acquired it is essential to get good paperwork and technical records for the LLPs. Technical records for LLPs should provide back-to-birth traceability. This is not always possible, and it reduces the number of parts to choose from," says Watson. "There is first the practice of swapping complete modules, such as the fan, LPC, HPC, HPT and LPT, between engines. There is also the practice of shop module changes. This is swapping the sub-assemblies of modules. These can include, for example, combustion chambers, cases, and complete rotors.

"As well as finding parts with the right LLP stub lives, the configuration of parts and airfoils between the mixed modules must be correct. The quality of the airfoils in terms of likely remaining time on-wing to the next shop visit is the main consideration," says Watson. "It is actually hard to find time-continued modules in the right condition."

Hill advises that if the plan is to build a core for 11,000EFC, then the LPT and fan/LPC should clearly have an LLP remaining life of at least 11,000EFC. "Care needs to be taken when mixing



In many cases it is possible to find time-continued modules that have airfoils in condition that will allow them to continue to operate for several thousand more engine flight hours (EFH). The market value of time-continued modules will be less than the combined cost of a shop visit and new LLPs for the same module.

modules, and when deciding on a shop visit workscope," says Hill. "A -3C1 core will only achieve an on-wing interval of about 6,000EFC, so there is also no point in overbuilding other modules."

The fan/LPC and LPT are likely to have sufficient airfoil condition and LLP life to continue operation, because of their long LLP lives and shop-visit intervals. Operators can therefore save costs by acquiring time-continued HPC/HPT modules. These will have the highest market value of all the engine's modules.

An ideal situation may be, for example, where the LPT and fan/LPC have at least 12,000EFC of remaining LLP time. These could be combined with a time-continued or fully expired -3C1 core that would need a full shop visit, or an overhaul and LLP replacement. It would then achieve 6,000EFC on-wing. The HPC/HPT could be put through a full performance restoration to get a second 6,000EFC interval prior to retirement of the engine after at least 12,000EFC, which is equal to six years of operation.

There will, however, be times when the HPC/HPT have some time remaining, and a time-continued LP module has to be replaced. This is more likely to be the LPT, since the fan/LPC has the longest LLP life and overhaul interval.

Operators also have the opportunity to acquire individual time-continued LLPs on the used market. These would be bought to replace parts with restricted lives that were installed in the engine in earlier years of operation. Their expiry would leave most of the other LLPs in the engine with several thousand EFCs left to operate. Examples of LLPs in the HPC are the stage 4-9 spool, and the HPC rear air seal. There are also P/Ns for three of the four LLPs in the HPT which have lives of 11,400-15,800EFC in the case of category C and B engines.

Shop-visit inputs

It is generally accepted that the large volume of parked and retired aircraft has increased the supply of engines to the point that the cost of full shop visits on different modules is higher than the market values of time-continued units.

"Operators need to consider a time-continued module's market value and time remaining against the cost of putting it through a shop visit," says Watson. "It is not easy to replace used modules with time-continued units at the right price."

The cost of the shop visit, perhaps together with the cost of new LLPs, has to be compared against the market value of the different modules.

In other circumstances the cost of a shop visit plus the value of one or two time-continued LLPs will have to be considered against the value of the different modules. "The market value of time-continued LLPs is a fraction of the cost of new parts," says Watson. "The value of individual LLPs will be pro-rated on the basis of remaining life and original life, and may then be discounted further."

For a full engine and modules, the cost of a full shipset of LLPs is $2.34 million, split between $460,000 for the fan/LPC, $627,000 for the HPC, $514,000 for the HPT, and $731,000 for the LPT. The list price of individual parts is $62,000-303,000.

It is rare for all modules to have their LLPs replaced at the same time. The HPC and HPT will have their parts replaced at the same shop visit, and the combined list price of LLPs for these two modules is $1.14 million.

On a module level, Hill estimates that a core performance restoration can start at $1.2 million, and full overhaul to replace a higher proportion of airfoils can reach about $1.4 million. Pelly estimates this can be as high as $1.6 million. An overhaul and installation of a full set of LLPs is therefore up to $2.7 million.

Hill puts the cost of the LPT shop visit, which is in most cases a full overhaul and involves the replacement of all airfoil parts and seals, at $350,000. Combined with the price of a full set of new LLPs, it takes the total to $1.1 million.

The cost of a full workscope of the fan/LPC is up to $200,000. Combined with LLPs it totals about $650,000.

Hill estimates the cost of a full engine overhaul, including all labour, materials and parts, and sub-contracted repairs, to be $1.9 million, while Pelly says it can be as high as $2.1 million. This excludes LLPs.

A full overhaul of an engine would include all modules. While this would probably include replacing LLPs in the fan/LPC and LPT, it might not necessarily include replacing LLPs in the HP modules. The total cost of this shop visit would be $3.2 million. This would have to be considered against the 25,000EFC and 30,000EFC lives of the LP modules, and the probable subsequent removal interval of 6,000-15,000EFC for the HP modules, depending on the thrust rating. A smaller subsequent shop visit on the HP modules, at a cost of $1.2-1.4 million, would provide an interval of another 6,000-15,000EFC. The $4.4-4.6 million cost would therefore provide an engine that could remain on-wing for up to 20,000EFC before any LLPs had to be replaced.

These costs have to be considered against the market value of an engine with a high maintenance status and long LLP life remaining. The initial cost of $3.2 million for a full overhaul and HP LLP replacement compares to an engine with 6,000EFC of life remaining and a market value of $2.5 million, as estimated by Tom McFarland, vice president of engine trading at AerSale.