There are many permutations airlines can use to acquire the spare engines required to maintain a reliable operation. Each method has its merits and cost factors. The parameters of determining spare engine requirements and assessing their costs are analysed.

The parameters of spare engine inventory requirements & costs

Airlines have a multitude of options for accessing spare engines. Besides straightforward ownership, they can pool engines or lease them for a variety of terms at differing rates. The economics of owning, pooling or leasing comes down to the engine type and its market value and shop visit cost. It is generally only economic to own spare engines if they are to achieve high rates of utilisation. It is generally best to lease spare engines which have low levels of utilisation. Airlines therefore have to determine their spare engine requirements to assess their most economic option.

Inventory requirements

Spare engine numbers are determined by first calculating the annual engine flight hour (EFH) utilisation of each type in the fleet. Ten A320s, powered by CFM56-5Bs, with an annual utilisation of 2,750 flight hours (FH) per year would generate 55,000EFH annually.

The shop visit rate or average interval between removals for all shop visits then determines the number of annual shop visits the fleet will have. Therefore, if the airline expects its CFM56-5Bs to have an average interval of 11,000EFH, it can expect to have an average of five shop visits each year.

The second factor that affects the spare engine requirement is the turnaround time (TAT) for the engine; that is from removal through the shop visit to reinstallation. This period has itself been reduced over the past decade to well over 100 days in some cases, but to about 45-50 days for many airlines and engine shops.

If the five engine removals can be managed so that they occur at even intervals, one at a time, it will be possible to minimise the number of spares required. A TAT of 50 days means that successive removals will result in the five engines being in the shop for a total of 250 days. This is known as 'days in process'. If the removals can be managed to occur in succession, without overlap, one spare engine will therefore be required for the fleet to cover the 250 days each year when the five engines are in the shop. This leaves 115 days a year when the spare engine is not required. If removals still occurred in succession and without overlap, up to seven removals and shop visits would result in 350 days in process. This could be managed with just one spare engine, leaving just 15 days out of process. The proportion of days in process of 365 annual days equates to 0.96. It is obviously not possible to have 0.96 engines, and so a single spare engine would be required. This would support a maximum of 14 aircraft with this utilisation and average shop visit removal interval *(see table, page 10)*, if the removals occurred in succession.

With the same annual utilisation and shop visit interval, a large fleet of 56 aircraft, four times the size, would have 28 engine removals per year and 1,400 days in process. This is equal to 3.84 engines. Again, if removals could be managed in succession, four spare engines would be required.

Confidence level

Because removals occur at random and not in convenient succession, an airline can only be confident that the number of spares calculated will give adequate protection 50% of the time. There is still a 50% probability that two of the seven annual removals for the fleet of 14 will occur simultaneously, and so two spare engines will be required at this time. The other five expected removals are then less likely to coincide, and so most of the time the airline can rely on a single engine providing enough coverage.

Despite this, airlines cannot risk aircraft being grounded due to lack of spare engines, and therefore need access to a higher number of spares. The Poisson distribution determines how many engines are required to give a higher confidence level. For the fleet of 14 A320s two spare engines are required for the airline to have adequate coverage 90% of the time. That is, to have a 90% confidence level *(see table, page 10)*. Three engines are required for a 95% or 97% confidence level. A 97% confidence level means the airline will be adequately covered for virtually all circumstances.

Although the 50% confidence level for a fleet four times the size (56 aircraft) requires four times the number of spare engines, the relative proportions for confidence levels of 90%, 95% and 97% are different. These are six engines for 90%, seven engines for 95% and eight engines for 97%. The small fleet requires three times the number of engines to increase a confidence level from 50% to 97%, while the large fleet requires twice the number of spares to increase its coverage from 50% to 97%.

The number of spares required for a 50% confidence level is a function of fleet EFHs, average shop visit interval and TAT. The number of engines required for a 50% confidence level, and higher levels of 90%, 95% and 97% are shown for a variety of aircraft types, with typical average removal intervals *(see table, page 10)*.

This illustrates the higher spare engine requirement of older types, due mainly to

SPARE ENGINE INVENTORY REQUIREMENTS FOR YOUNGER & OLDER TECHNOLOGY FLEETS

Engine type Application	CFM56-5B A320	CFM56-7B 737NG	CFM56-3 737-300	JT8D 737-200 (passenger)	JT8D 727-200 (freight)	JT8D-200 MD-80
Fleet size	14	20	20	20	20	20
EFH/year	77,000	112,000	100,000	88,000	72,000	100,000
Average SV interval (EFH)	11,000	10,000	8,000	6,000	9,000	6,500
Average annual engine SVs	7.0	11.2	12.5	14.7	8.0	15.4
Days in process	350	560	625	733	400	769
Actual	0.96	1.53	1.71	2.01	1.1	2.11
Number of spare engines for 50% confidence level	1	2	2	2	2	3
No spare engines-90%	2	3	4	4	2	4
No spare engines 95%	3	4	4	5	3	5
No spare engines 97%	3	4	5	5	3	5

Engine type Application	CF6-50 DC-10-30	CF6-50 A300B4F	JT9D-7Q 747-200F	CF6-80C2 747-400	PW4000-112 777-200	CFM56-5C A340-300
Fleet size	10	10	10	10	10	10
EFH/year	105,000	24,000	144,000	192,000	96,000	192,000
Average SV interval (EFH)	7,400	4,000	7,000	13,000	11,000	12,000
Average annual engine SVs	14.2	6.0	20.6	14.8	8.7	16.0
Days in process	709	300	1,029	738	436	800
Actual number	1.94	0.82	2.82	2.02	1.20	2.19
Number of spare engines for 50% confidence level	2	1	3	3	2	3
No spare engines-90%	4	2	5	4	3	4
No spare engines 95%	5	3	6	5	3	5
No spare engines 97%	5	3	6	5	4	5

shorter shop visit intervals, but also to more engines on the aircraft.

These calculations only reflect the circumstances of mature fleets with a steady stream of removals. Modern aircraft types have engines which can be expected to have first on-wing runs in the region of 18,000EFH, with the variation of most removals occurring at plus or minus 4,000EFH this figure. A new fleet of A320s would not expect to have the first engines removed until the oldest aircraft had accumulated 14,000EFH. At typical airline rates of utilisation, this would be after more than five years of operation, although some aircraft would not have removals until after six or seven years. Fleets of new aircraft can therefore operate for the first few years without any spare engines, thereby reducing the costs of inventory. Some airlines will still need some coverage in the event of unscheduled removals forced by failures or foreign object damage. Since the number of removals for these events alone is a small, airlines may be prepared to take the risk of accessing an engine from a pool or on a short-term lease when required.

It is only when engines start being removed regularly that airlines cannot afford to risk being without permanent coverage and need to own their own powerplants.

Permanent coverage

The number of spare engines required for a 50% confidence level therefore shows the number that would be required most or all of the time due a constant stream of removals. The example of 14 A320s *(see table, this page)* would use the single spare engine 96% of the time (350 days in process) throughout the year. The second and third engines for a 90-97% confidence level would not be required on a permanent basis.

One way of calculating the cost of owning engines is the annual depreciation, plus interest foregone from having the funds invested in the engine.

Engines for modern aircraft may be depreciated over 15 or 20 years, or the length of time they spend in the fleet, but can also have a high level of residual value. This will be hard to predict, so depreciation over 15-20 years to zero is prudent, with a residual value providing upside for the airline.

For example, a CFM56 purchased at $5 million will have an annual depreciation cost of $250,000 when written down to zero. Interest foregone each year at 6% as a result of the investment would be $300,000. Annual ownership would therefore be $550,000.

Engines for older types, such as the 727-200 or DC-10-30, should be depreciated to zero over a short potential remaining life, of say five years, since they carry a high risk of having a low residual value. Airlines operating older aircraft may also change fleet plans to a younger type earlier than originally expected, but still realise a weak residual value, even if they are disposed of after just three or four years.

A CF6-50, with a market value of $900,000, depreciated over four years would have an annual cost of $279,000.

Annual depreciation costs of younger and older generation engines are shown *(see table, page 14)*. These rates are based on current market values and assume depreciation is to zero over 20 years for younger generation engines and four years for older generation powerplants. Annual interest charged is at 6% of the full engine value.

It is possible to lease engines over the long-term, for seven years or more, but this will generally cost more than the depreciation and interest foregone.

Long-term lease rate factors are in the region of 1.1% per month. An engine sold for $5 million will therefore have a lease rate of about $55,000 per month. The airline will therefore pay more than $5 million for a term of 90 months or longer, putting airlines at a disadvantage for transactions longer than seven years.

Leases therefore tend to be used out of practical necessity rather than financial efficiency. They do have the advantage of providing off-balance sheet financing.

Airline lessees have the responsibility of paying maintenance reserves for when a shop visit comes due.

Long-term leases provide the same coverage as owned engines, that is a confidence level of up to 50%.

Airlines will still take advantage, however, of the strong residual value performance of engines by arranging sale and leaseback transactions with specialist engine lessors. This has the advantage of releasing equity, and is commonly done if an airline is planning to phase out a fleet.

As can be seen from the table, the number of owned engines required to give a 97% confidence level is 10-15% of the number of installed engines in most cases. It is only lower where aircraft utilisation is low in relation to shop visit removal interval, as in the case of a 727 freight operation. Many airlines do not have the finances available, or the strength in their balance sheets, to own the number of engines required for a 50% confidence level and so can be forced into long-term leases. These have the advantage of providing an off-balance sheet technique for financing.

Irvin Lucas, vice president of sales and marketing at Volvo Aero Services estimates that the proportion of engines that are owned, or on sale and leaseback transactions or long-term leases are 65%, 5% and 10%. The remainder of spare engines are provided by short- and medium-term leases and accessed through pools.

The choice between ownership and long-term leasing has become more academic in recent years with the original equipment manufacturers entering the market. On ordering a new fleet airlines are now offered full engine support packages. These provide maintenance and spare engine support under a single cost per EFH.

More airlines are now planning their operations with shorter horizons. Airlines

Airlines acquiring new fleets powered by types like the V.2500 benefit from the high reliability and long first on-wing runs of these engines. This means a small number of shop visits are experienced during the first years of operation, allowing these airlines to minimise the maintaining of a spare engine inventory.

with new fleets may only operate aircraft for seven or eight years. The ability to avoid having spare engines for the first four or five years because of high reliability means that airlines will only require long-term spare engine coverage for the last three or four years that the fleet is with the airline. In this case medium-/long-term leases can be a more economic solution than owning spare engines, since lease payments over the term will be less than the capital cost of the engines, with the added advantage of leasing providing off-balance sheet financing. Owned engines can still provide residual value benefits, but carry a risk for the airline.

Incremental coverage

The cost of ownership, depreciation and interest is generally only economic if the engine is utilised all year round and over the long-term. It is excessive compared to the cost of leasing an engine for a short-term.

In the case of the 14 A320s requiring one engine for a 50% confidence level, the second spare engine, for a 90% confidence level, will only be required when two removals occur simultaneously. The second engine would then only be utilised while the first removed engine was in the shop, that is, for 50 days. This may occur once or twice in the year, so only for 50 or 100 days. It would be economic to acquire a second engine on a short-term lease or via another method for this amount of time.

Short-term requirements can be exacerbated by removals occurring in clusters. Fleets delivered over short periods run the risk of first engine removals occurring close together, which can cause spikes in short-term demand for engines. Examples are the CFM56-7 and V.2500, with many first run engines in the global fleet being removed at the same time. This can lead to shortages of spare engines, raising short-term lease rates and causing large spikes in engine inventory costs. Some airlines can be forced to buy new engines from the manufacturers. The airlines can later benefit, however, from a few spares of types like the CFM56-5B, CFM56-7 and V.2500 being on the market, making re-sale values high.

Medium-term leases are for terms of six months up to about four years. They also incur monthly lease rates and lessees maintain maintenance reserves. Medium-term leases can be used for coverage of 50-80% confidence levels. They therefore account for the first one or two engines used in the event of multiple removals. In small fleets this coverage may only be a few months, and so short-term leases are only required, obviating the need for medium-term leases, since short-term leases fulfil the requirements.

Medium-term leases normally arise when shorter-term leases are extended. An airline may take a few engines on a short-term lease to cover some one-off removals, and then find it has a series of these removals which need to be covered for a longer term. This typically occurs when airlines get peaks or clusters of removals. Airlines with new fleets that start to get engine removals may experience them in clusters; medium-term leases also cover these situations.

Shorter-term leases last only a few months, and incur daily lease rates and maintenance reserves paid by the lessee to the lessor. Lease rates are relatively high. A CFM56-3, for example, may incur a daily rate of $2,000-3,000, equal to a monthly lease rate of $60,000-90,000. This is equivalent to a monthly lease rate factor of 1.5-2.0%, since the market value of a CFM56-3 is in the region of $4.5 million, although highly variable. Short-term leases are therefore only economic if the engine is actually required for a few months each time.

Typical market values, shorter-term lease rates and engine reserves charged by specialist engine lessors for a variety of younger and older generation engines are shown *(see table, page 14)*.

Pooling

Pooling is a system where several airlines can acquire spare engines from one group of engines. This has often been instigated by large airlines which have acquired a large number of spare engines to cover all circumstances, and find they have engines which are not being fully utilised. Spare engines can then achieve higher rates of utilisation by being shared with other carriers. Each airline can determine the number it requires for a 97% confidence level. Combining the requirements of several airlines can effectively achieve a large fleet and a more economic number of engines to supply the whole fleet. That is, 14 A320s require three spares for a 97% confidence level *(see table, page 10)*, while 56 aircraft would require eight engines for the same confidence. The inventory cost per aircraft is therefore reduced for a combined fleet. Having one pool for several carriers and a larger fleet would also reduce the need to acquire engines on short-term leases, since the probability of there being a spare unit available for all removals would be increased.

Engine pools often feature the major engine supplier providing condition monitoring and engineering services, access to line replaceable parts, shop-visit planning advice and line maintenance and AOG (aircraft on ground) support. Pools can also provide airlines greater control over their maintenance costs and shop-visit turn times.

Shop visit costs can be averaged for all pool members. Maintenance reserves are paid by each on the basis of each operator's shop visit rate divided by the average shop visit cost. An availability fee, to cover the capital costs of the engines, can be related to the operator's own average number of engines in process at any one time, divided by the average number of engines in process for the whole fleet multiplied by the number of spare engines multiplied by the monthly costs per engine.

Shannon Engine Support (SES) provides a pooling service for CFM56 engines powering the A320 and 737 families. "We have a stock of engines and pool members pay an access fee," says Roger Welaratne, senior vice president of operations at SES. "Each airline can say what type of service it wants, whether it is long-term or short-term coverage. Airlines will pay a fee for guaranteed availability of an engine for short-term lease. With this guaranteed availability fee airlines can be provided with an engine within 24 hours for AOG situations. Additional lease fees are paid and both our short- and long-term leases incur restoration charges, like maintenance reserves, when the engine is used. A small carrier which may only have two or three shop visits each year will incur a lower cost this way than taking an operating lease for 12 months."

Some airlines will take the risk of not being a pool member. In the event of an AOG the airline will then have to rely on the shorter-term lease or spot market to supply coverage. This may be more economic than constantly paying a pool fee, but risks the aircraft being stranded for longer in the event of a problem.

Willis Lease Finance Corporation (WLFC) does not have a formal pooling arrangement, but president Charlie Willis provides access to its engines for short-term periods if they are available. "We have a virtual pool as a consequence of this, since we often have engines coming off lease from longer terms. They can be used for a short period of time before being re-leased on longer terms. We can thus benefit from additional revenues, without having to charge formal pool fees to airlines that require them for a short period. This is different to formal pooling arrangements which charge access or membership, as well as usage fees in the event of a removal. We only charge a daily rate, to cover the cost of the asset, and EFH rate, for a maintenance reserve," says Willis.

Older engine types

Instead of access to a pool of spare engines or short-term leases for short-term requirements, airlines can rely on the spot market for support. This is a low risk option where there are a large number of spare units on the market at a low value. This is generally the case for older types. The most common examples are the 'Baby' JT8D and JT9D, but more commonly the JT8D-200 and CF6-50 series.

The large number of these engines that are available on the used market has reduced their market values to a level where it is more economic to either buy time-continued engines or have a module/core exchange than put them through a shop visit. This phenomenon has occurred several times in the history of the JT8D, where recessions have seen large numbers of Stage 2 narrowbodies parked and a glut of engines materialising. Time-continued engines have been taken from aircraft and bought by airlines. The trend has been reversed when aircraft have been put back into service, increasing the value of JT8Ds. The value of JT8Ds and JT9Ds will now be permanently low, and airlines operating types like the 727, 737-200, 747-200 and DC-10-30 may find it more

SPARE ENGINE INVENTORY COSTS FOR YOUNGER & OLDER TECHNOLOGY FLEETS

Engine type Application	CFM56-5B A320	CFM56-7B 737NG	CFM56-3 737-300	JT8D 737-200 (passenger)	JT8D 727-200 (freight)	JT8D-200 MD-80
New cost ($ million)	5.2	5.8	4.2	N/A	N/A	N/A
Market value ($ million)	4.0	4.5	2.5	400	450	1,300
Annual depreciation cost $K	575	640	465	125	140	400
Short-term lease rate ($/day)	2,300	4,500	2,500	400	450	1,300
Maintenance reserve ($/EFH)	185	190	135	90	110	125
Fleet size	14	20	20	20	20	20
Number owned engines	1	2	2	2	2	3
Removals covered by owned engines	4	8	8	8	5	12
Removals covered by short-term leases	3	4	5	7	3	4
Total depreciation & short-term lease costs-$	**1,240,000**	**2,255,000**	**1,745,000**	**668,000**	**435,000**	**1,660,000**

Engine type Application	CF6-50 DC-10-30	CF6-50 A300B4F	JT9D-7Q 747-200F	CF6-80C2 747-400	PW4000-112 777-200	CFM56-5C A340-300
New cost ($ million)	N/A	N/A	N/A	8,000	12,500	5,200
Market value ($ million)	900	1,700	4,000	5,000	11,000	4,700
Annual depreciation cost $K	100	100	190	850	1,375	575
Short-term lease rate ($/day)	1,500	1,500	1,700	3,000	8,000	3,000
Maintenance reserve ($/EFH)	250	450	225	275	300	285
Fleet size	10	10	10	10	10	10
Number owned engines	2	1	3	3	2	3
Removals covered by owned engines	8	4	12	12	8	12
Removals covered by short-term leases	6	2	9	3	2	4
Total depreciation & short-term lease costs-$	**1,615,000**	**460,000**	**2,720,000**	**3,710,000**	**3,980,000**	**3,350,000**

economic to rely on the spot market for spare engines.

A shop visit for a JT8D can cost about $1.1 million, and a set of LLPs $0.5 million. This compares to market values of $300,000-400,000 for a time-continued JT8D-9. Similarly, a shop visit for a CF6-50 can cost $1.5-1.75 million and set of LLPs more than $2 million. This compares to market values of $900,000 for time-continued engines.

These two examples illustrate how it is more economic to acquire time-continued engines and sell run-out engines than put them through the shop. For example, an airline may buy a time-continued CF6-50 for $900,000 and sell the run-out engine for $500,000 at a net cost of less than $0.5 million. More importantly, however, the airline incurs a large saving by avoiding the shop visit cost of about $1.7 million for the engine. This ignores the possibility of even higher costs incurred by the need to replace LLPs.

Since time-continued engines have only about half their remaining on-wing life left, the average interval between each engine removal will be reduced from the full on-wing time of 7,400EFH to about 3,700EFH or less. This will therefore double the number of engine removals each year. Assuming an airline is able to acquire all its engines from the aftermarket, a fleet of 10 DC-10-30s operating 3,500FH a year *(see table, page 10)* will therefore generate 105,000EFH annually and have an average of 28-30 engine removals each year, instead of 14 if the airline kept its own inventory. This exchange would have the added benefit of almost zero engine shop visit costs.

Although it is more economic to own spare engines that achieve a high utilisation, few airlines have the financial resources to own all the engines they require. Airlines therefore depend on specialist engine lessors to provide some of their engines on medium- and long-term leases.

Although engines are at depressed values this will only be for a short period. The superior economics of acquiring time-continued engines rather than putting removed units through a shop visit means airlines will exhaust the supply of engines on the aftermarket, forcing up their values. Airlines will therefore have to put engines through the shop and maintain an inventory on a long-term basis. This is especially the case where a long-term commitment has been made to large fleets of older aircraft, for example, in the case of a large freight carrier with a fleet of 727-200s.

An airline may, however, be able to deal a portion of its removals by acquiring time-continued engines. This will generate some savings where possible. The percentage of removals that can be dealt with by the more economic option of exchanging run-out engines with time-continued ones will depend on the effectiveness with which an airline's engineering department takes advantage of a depressed market.

The annual depreciation charge for a CF6-50 will be higher than the cost of $279,000, since engines acquired for an inventory will have been bought at higher values than current depressed levels. A fleet of 10 DC-10s will require two engines for a 50% confidence level. Annual ownership of these will be in the region of $400,000 each, a cost that will of course reduce to zero once the engines are fully depreciated. This cost will be incurred in addition to the 10 shop visits for which these two spare units will provide coverage, plus replacement of LLPs when required.

Additional engines would be required for short periods for four to six additional removals occurring simultaneously for a few occasions during the year. These could be catered for either by short-term leases or by an exchange with a time-continued engine. A short-term lease for a CF6-50 costs about $1,500 a day, or $90,000 for a two-month period. Maintenance reserves of $250 per EFH would also have to be paid, for about 600EFH over the two month lease, equal to $150,000 for each engine. This would be equal to a total cost $240,000 per engine.

This may be required five times during the year, plus the cost of five shop visits, at a cost of about $8.5 million. Five two-month leases plus the five shop visits they would cover would cost in the region of $9.7 million.

These short-term requirements could instead be covered by 10 engine exchanges at a total cost of about $5 million.

Inventory costs

Where fleets of young engines cannot rely on the spot market, engines required for a 50% confidence level will be owned. Additional engines for higher coverage will probably be acquired on short-term leases in small fleets. Larger fleets are more likely to see these spikes in demand being satisfied with medium-term leases.

Older fleets will also have to rely on owned and short-term leased engines for most of the time.

Taking some of the fleets described and their spare engine inventory requirements based on assumed rates of aircraft utilisation and average shop visit interval, the annual engine inventory costs can be calculated *(see table, page 10)*.

These are based on an assumed number of shop visits for which the owned engine can provide coverage, and the annual depreciation costs of owned engines plus the short-term lease rates and maintenance reserves of engines acquired for periods of 2 months to cover the remaining one-off removals and shop visits of 50 days' turn time *(see table, page 14)*.

For example, for the fleet of 14 A320s, one owned engine may cover four or five of the annual removals *(see table, page 14)*. This will incur an annual depreciation cost of about $575,000 for one CFM56-5B or V.2500. A further two or three removals would each have to be covered by short-term leases of 50 days. These would each incur a cost of about $223,000. The total annual engine inventory cost for this fleet covered in this way is $1.24 million *(see table, page 14)*. This is equal to $16 per EFH across the fleet. A fleet of 56 aircraft could be covered by five owned engines, covering 20-25 of the 28 anticipated annual removals, incurring an annual depreciation charge of about $2.9 million.

Engine inventory costs for fleets covered by a combination of owned engines and others acquired through short-term leases are shown for a variety of types *(see table, page 14)*.

The remaining 3-8 removals would be supported by a combination of medium- and short-term leases, costing about $1.1 million. Total inventory cost would then be $4.0 million, or $13 per EFH.