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The economic cost of FOD to airlines

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SUMMARY

The largest 300 airports collectively service slightly fewer than 55 million movements per year, and see up to 70,000 FOD incidents. Depending on traffic and the specifics of their operating environment, this FOD causes airlines to incur (collectively) direct costs as high as US$20 million per airport per year. FOD costs airlines US$263K per 10,000 movements in direct maintenance costs. Overall spend for the top 300 airports is US$1.1Bn.

If the indirect cost of delays, plane changes, fuel inefficiencies, etc., are added then the cost of FOD increases by a multiple of up to 10x, to US$12 billion pa.

Airlines currently treat these expenses simply as the "cost of doing business". It is considered normal that most engines have blended blades. Tyre contracts are priced to include replacements due to FOD damage. However, it is clear that if the FOD were removed these costs would similarly disappear. FOD must therefore be considered not only a safety risk, and a nuisance, but an area where airlines might start to claw back significant value from operations.

	Per 10K movements	**Per Flight**	**Per Passenger**
Direct Cost of FOD			
Engine maintenance spend	$205,000	$21	$0.10
Tyre replacements	$57,000	$6	$0.03
Body damage	$926	$0.1	$0.0005
Total Direct Cost of FOD	$263,000	$26	$0.13
No. of FOD events			
Engines			
Total No. of Engine FOD events	*3.1*	0.03%	-
Tech test/inspection	*1.5*	0.02%	-
Blades blended	*2.1*	0.02%	-
Blade pairs replaced	*1.7*	0.02%	-
Engines replaced	*0.03*	0.00%	-
Tyres			
Total No. of Tyre FOD events	*9.7*	0.10%	-
Total No. Tyres replaced	*3.4*	0.03%	
Replaced for gouge	*0.2*	0.00%	-
Replaced for tear	*2.7*	0.03%	-
Replaced for puncture	*0.6*	0.01%	-
Tyres that fail retread due to embedded FOD	*6.3*	0.06%	-
Body damage	*2.6*	0.03%	-
Total No of FOD events	12.8	0.13%	-

NOTES & COMMENTARY

Sources

There are many people who deserve thanks for making this work possible, however almost all of them prefer not to be named. So let us simply say that for anything we got right someone else deserves the credit, while any misstatements, faults, errors, or omissions are entirely the responsibility of Insight SRI Ltd.

The best data in this report comes from a generous if anonymous US airline that shared the maintenance logs for one of their hub airports. These logs document the occurrences of the engine inspections on and off the flight-line; the number of blades blended; the number of engines replaced; tyres replaced; etc.,. Using this data, we have been able to determined the frequency of the different types of FOD events.

However, the numbers are not without flaw. At the very least, although the FOD damage was reported at the hub airport it could have occurred elsewhere. Likewise, there could be damage occurring at the hub which was reported at other airports (whose data we did not see). We have tried to balance the raw data against common sense and operational realities, but there is certainly room for improvement in these numbers.

Likewise, the cost data is not as robust as we would like. Ideally, we would work costs from the bottom up. To our own disappointment, we haven't found any sources with sufficiently reliable numbers to let us do so. Most of costs are based instead on a top-down number from a second major US carrier, 'Carrier-2' *(to distinguish them from 'Carrier-1', who shared their maintenance records)*.

Carrier-2 estimated their spend per month on engine FOD damage, and although the types of damage and the events themselves are very well documented the airline has not examined their costs in the same detail. The best number they could give us, and the only number we have, is a top-down estimate. They indicated engine spend of $1.8M fleet wide per month, with values ranging anywhere from $1M to $2M. Our calculations are based upon their given average, but we are aware that 1.) this seems high, and 2.) using the possibly more reasonable lower value would almost halve the cost figures we quote.

Therefore, although answers offered here are the best we can provide, we are more than open to comments and suggestions for how to improve it. I appeal to you, the readers, for help in this regard.

This work was originally done as part of a project for Qinetiq Airport Technologies, who are themselves collecting more and better information on FOD and its costs. Qinetiq's Tarsier automatic FOD detection system is the de-facto industry standard, mostly by virtue of being the only system in active commercial operation anywhere in the world at the time of this writing (March 2008).

The Frequency and Direct Cost of FOD Events

1. Engine damage

'Carrier 1', a large (but anonymous) US commercial airline reported 117 engine events at a single airport over a twelve month period. From those events, they replaced 65 blade pairs, blended 80 blades, and made more than 57 "technical" inspections (e.g. bore-scope, fluorescent dye, eddy check, etc.,).

FOD Engine events for 'Carrier-1'

No of blades in event	# incidents Reported	# blades Blended	# blade pairs replaced	# of technical inspections
TOTAL	117	80	65	57
1	83	49	8	34
2	17	6	16	10
3	4	3	3	0
4	9	12	20	8
5	3	10	0	5
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	0	0	0	0
11	0	0	0	0
12	0	0	0	0
13	0	0	0	0
14	0	0	0	0
15	0	0	0	0
16	0	0	0	0
17	0	0	0	0
18	0	0	18	0
19	0	0	0	0
20	0	0	0	0
21	0	0	0	0
22	1	0	0	0
23	0	0	0	0
24	0	0	0	0
25	0	0	0	0

Note: some events may include tech inspection, multiple blends, and pair replacements

Generally speaking, the events described in the table above were found during non-routine flight line checks. As blade pair replacement and blending usually require taking the aircraft out of service while work is done, the aircraft involved above were probably pulled from the flight line – meaning that a replacement aircraft had to be found *(the associated cost of changing aircraft like this is an <u>indirect</u> cost*). Even assuming the work was a simple blend (Type I) that could be done in-situ (rather than a complex Type-II event, which requires >70 process steps and often means 'dropping' the engine) it takes several hours. Aeroservices Ltd. benchmarks Type I repairs as lasting 5-8 hours, with an aircraft out of service for a total of 8-12 hours for a basic blending. The 5-8 hour time frame is confirmed by GE Aviation Services, whose "On Wing Support Team" suggests that blending can be done in five hours or less (excluding identification, pre-inspection, and other activities around bringing the aircraft in and out of service).

Boeing suggests the average cost to blend a single blade is on the order of $4,000, and Rolls Royce has suggested a cost of $5,000. Note that these figures are not used in making our cost assessment. We have stuck to the top-down spending estimate made by the second airline, Carrier-2. Carrier-2 suggests that repairing these types of engine events, scaled to Carrier-2's levels of traffic, costs between US$1 and US$2 million per month. The fleet-wide average was $1.89 million over roughly 50,000 flights (100,000 movements) during Spring 2007, which is the equivalent of $205,000 per 10,000 aircraft movements.

Note, these values contrast sharply with the "average engine FOD cost" of roughly $0.5M per engine event that is so often quoted by OEMs. This is probably because the OEMs only hear get involved in the catastrophic damage events, and the day-to-day minor events are handled by the airlines. Our airline data suggests that actual spend on FOD engine damage tends to be much lower per event than previously published estimates, although the number of events is much higher.

2. Tyre damage

There are two distinct types of tyre events: 1.) Tyres which are visibly punctured or torn by FOD and which need to be replaced, and 2.) Tyres which have embedded FOD that is not visible during normal inspection, but which causes the tyres to fail retread.

Puncture or tear replacement data comes from 'Carrier-1', a major US carrier who experienced 32 punctures requiring replacement, and 158 tears (of which 80% required replacement and 20% were within service limits) and 7 gouges (all of which required replacements) at one airport over a twelve month period. This is equivalent to a rate of 5.3 replacements per 10K movements.

Tyres cost an average $3,261 (*source: Michelin and Goodyear, for standard tyres on Boeing and Airbus aircraft*), for a cost of $17,283 per 10K movements. Interestingly, most airlines are supplied tyres based on a cycle index contract. In the case of Carrier-1, the value of the tyres replaced over twelve months was just under $0.5 million, but the airline only paid roughly $50K above contract for the tyres. For this airline, although eliminating at the airport might save up to $0.5M per year in overall economic value, the near term impact on their own balance sheet is much less as the existing tyre contract already includes the cost of replacements due to FOD.

3. Unseen tyre damage

ATA statistics for US airlines show that 2.5% of all tyres sent for retread fail due to embedded FOD. Generally this is embedded, but previously undetected FOD that is only found during the retread process. Each tyre failing retread saves $1,312 (the cost per retread) but costs the same $3,261 per tyre average for a new replacement. Aircraft tyres are sent for retread every 100 flights *(source: testimony to the Canadian Department of Transport)*. The net cost for tyres failing retread is therefore $39,509 per 10K movements.

Retread Rejection Rates Due to FOD
for 737 &757 Main Gear Tires

Airline	2003-04
Delta	3.7%
Air Canada	2.6%
American	4.2%
ATA	1.3%
Southwest	1.6%
Aloha	2.4%
Industry Average	**2.6%**

Source: This table shows rejection rate for H40x14.5-19 tyres. Different rejection rates are found on other tyre sizes and aircraft types. Source: International AOA Expo, 2007 Session 8, http://www.aoaexpo.com/2006sessions.html

The interesting point on tyres is that generally it is not the airlines who would benefit immediately from a reduction in FOD, but the tyre companies. Most airlines are committed to cycle index/availability contracts already priced to include a punctures and retread failures. Therefore the tyre benefits from FOD reduction will first be seen by the tyre companies, and airlines will only benefit once the reduce number of replacements has been documented, and they have an opportunity to renegotiate contracts.

4. Body damage (skin / hull / airframe)

We do not have reliable data from civil aviation markets on FOD damage to skin or airframes. The only comparable information comes from USAF and USANG (Air National Guard) data for FOD damage to jet powered transport aircraft. However, although the military data is useful for costs, and the distribution of those costs, we have no baseline for damage event frequency.

We have therefore simply estimated that ‘skin’ events happen half as often as tyre events, and fewer than one in twenty skin events involves airframe damage.

At an average cost of $287 per skin damage event and $1,251 per event involving the airframe, this makes the total cost contribution from FOD at 5.3 tyre events per 10K movements ÷ 2 = 2.65 body / hull events per 10K movements, at a cost of $287*2.65 + $1,251*2.65/20 = $926 per 10K movements. This is less than 2% of the FOD tyre cost, and vanishingly small compared to spend on engine repair.

Aircraft Skin Damage and Repair
Cost Distribution (US$0's)

$100	47.0%
$300	34.0%
$500	9.5%
$700	7.0%
$1,000	2.0%
$1,500	0.2%
$2,000	0.2%
$5,000	0.1%
$10,000	0.1%
$15,000	0.01%

Airframe Damage and Repair
Cost Distribution (US$0's)

$2,000	4.8%
$3,000	18%
$5,000	20%
$7,000	40%
$10,000	8%
$15,000	7%
$20,000	2%
$25,000	0.1%
$50,000	0.05%

Indirect costs

1. Direct v Indirect cost multiple

We estimate the indirect cost of FOD to be roughly 10x the direct (maintenance expense).

There is no case study or specific example of the indirect costs of FOD damage. The closest parallel we can make is with apron safety events. According to the US Flight Safety Foundation (FSF) for apron safety events, the indirect costs are 12x to 13x direct costs.

FSF Exec VP Bob Vandel gives examples of a catering truck driving into an aircraft that caused direct costs of just $17,000, but indirect costs of $230,000 for a total of $247,000; and of a jet-way operator striking an airplane – incurring direct costs of $50,000 and indirect costs of $600,000 (*source:* '*Equipment Damage and Human Injury on the Apron, Is it a Cost of Doing Business?', Bob Vandel, ISASI 2004).* In other apron safety and apron damage events the indirect costs were similarly 12x and 13x the direct damage costs.

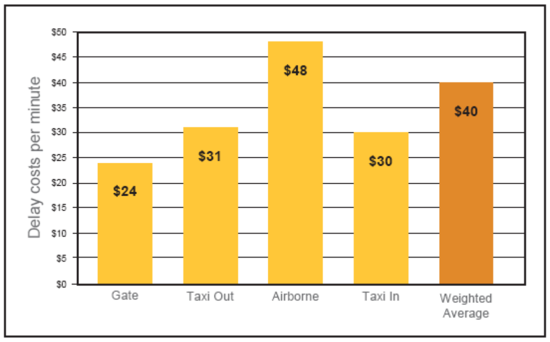
Though the indirect costs are not allocated to individual categories, the Flight Safety Foundation has created a list of indirect cost categories (*source:* '*Flight Safety Digest' December 1994, The Dollars and Sense of Risk Management and Airline Safety*), to which we have added some FOD-specific costs in creating a list of thirty three indirect FOD cost categories:

1. Airport efficiency losses
2. Carbon / Environmental issues
3. Change of aircraft
4. Close airport
5. Close runway
6. Corporate manslaughter/criminal liability
7. Cost of corrective action
8. Cost of hiring and training replacement
9. Cost of rental or lease of replacement equipment
10. Cost of restoration of order
11. Cost of the investigation
12. Delay for planes in air
13. Delays at gate
14. Fines and citations
15. Fuel efficiency losses
16. Hotels
17. In-air go-around
18. Increased insurance premiums
19. Increased operating costs on remaining equipment
20. Insurance deductibles
21. Legal fees resulting
22. Liability claims in excess of insurance
23. Loss of aircraft
24. Loss of business and damage to reputation
25. Loss of productivity of injured personnel
26. Loss of spares or specialized equipment
27. Lost time and overtime
28. Missed connections
29. Morale
30. Reaction by crews leading to disruption of schedule
31. Replacement flights on other carriers
32. Scheduled maintenance
33. Unscheduled maintenance

2. Delays

Delays are an example indirect costs, and would be part of the 10x direct v indirect multiple described above. Values for delay are taken from a Sabre study of indirect costs. They found a weighted average of $40 per minute per aircraft. A NASA study of airport delays showing the average delay on taxi-out times in US airports to be 9.56 minutes, with a delay of 3.81 delay minutes for taxi-in times. In-air delay times can be inferred taken from ATA air flow and traffic smoothing data, and from anecdotal evidence from YVR and MSP airports indicating that roughly 1 in 500 aircraft are required to do a go-around in the normal course of operations.

Cost of Delay per Minute, per Aircraft



Source: Sabre, http://www.sabreairlinesolutions.com/products/pdfs/OnTimePerform.pdf

US airports generally do not record the amount of time a runway is shutdown for FOD. By contrast, some of the larger European airports do. Data from two of the larger European airports indicates that their runways are shut down for an average 200-240 minutes per month due to FOD and wildlife, and that in excess of 90% of that closure time is due to FOD. One European airport went on to anecdotally suggested that up to 1% of their runway related delays are FOD related.

Combining all of the above, a large airport of roughly 400,000 movements pa (33,300 per mo) will see 90%*240 minutes = 216 minutes of delay due to FOD. The 33K movements represent some 17K flights, each of which experiences an average 9.56 + 3.81 = 13.37 minutes of delay, up to 1% of which is due to FOD (2,228 minutes). Lastly, in air delays and 'go-arounds' contribute an additional 0.2 minutes (if the same 1% are assumed to be FOD related).

All told, this is roughly 2,230 minutes of delay per month, or 667 minutes delay per 10K movements due to FOD. At Sabre's US$40 per minute this means FOD causes delays with an associated cost of $26,740 per 10K movements. At large airports the cost can come to well over $1 million per year.

This $1 million pa from delays is included in 10x direct v indirect cost multiple.

3. Fuel inefficiency

Engines operating efficiency drops slightly as blades are blended. As the blades are only blended as a result of FOD ingestion, FOD drives slight increases in fuel consumption.

Assuming a Boeing 767 with fuel capacity of 23,980 US gal, and a fuel price of $2.052 per gal (Apr 07, source ATA). IATA data indicates that the fuel capacity consumed on a typical flight is roughly 60% of aircraft capacity, which for the 767 comes to a cost of $29,524 per flight. For most aircraft in a typical fleet, the average engine in service will have at least 30% of its blades blended (Source: GE Engines), and up to 90% of the aircraft in a typical fleet have blended blades (Source: Delta Airlines). Blending can drive an efficiency loss of 0.5% (GE Engines, Pratt & Whitney). For the 767 example above, this would increase operating costs by $147.85 per flight. Note that this indirect fuel costs alone is more than three times the direct engine costs per flight ($47).

Safety perspective: FOD as a runway incursion?

Possibly the hottest topic in safety is runway incursions. Not only is this where most of the safety spending is taking place, but as of Feb 2007, in the United States the FAA is being required to make regular report to a congressional subcommittee on runway safety and incursions.

It is relatively easy to argue that FOD is simply an invisible runway incursion. Severe FOD incidents are just as dramatic as an incursion. The March '07 FOD incident in Dubai is a good example of how dramatic a FOD strike can be, with a Biman Bangladeshi Airways Airbus skidding down the runway in a shower of sparks and the entire airport closed for eight hours.[1] Fortunately, in that instance there were no fatalities but the potential for a full-on tragedy was clear, and only narrowly averted.

Where FOD surpasses normal 'incursions' is that the number of near misses is far, far greater. Incursions are rare, but there is almost always some sort of FOD on the runway. Also, we know from airlines having to regularly blend or replace blades, tyres, and what-not that minor FOD strikes are a regular occurrence.

Previously, FOD on the runway was easy to ignore as there simply wasn't much anyone could do about it. Best practice for airports meant manual inspections (four times daily in the best European airports, fewer in the US). That situation has changed. New FOD detection technologies (from Qinetiq, Stratech, etc.) mean that FOD can now be monitored and found in near-real time. The introduction of these new sensors (typically cameras, radar, or combinations of the two) may mean that FOD will find itself commanding the similar respect and severity of threat as runway incursions.

'What happened to "US$4Bn"?'

People familiar with FOD will be used to seeing a $4Bn value assigned to the cost of FOD. This hasn't changed, but our approach has let us define things more tightly.

Our value of $1.1 Bn for the direct cost of FOD is lower than the familiar Boeing number, but out overall assessment of the overall market is much larger once indirect costs are added.

The $1.1 Bn number is for:

- Direct maintenance costs only
- Only considers commercial jet traffic at the largest 300 airports
- Excludes indirect costs
- Excludes the value of FOD to the airport

It should be noted that if our numbers are expanded to include all commercial airline traffic, and not just traffic at the largest 300 airports, then our cost of FOD value rises to match the Boeing $4Bn figure.

Our number of $1.1Bn is a bit smaller, as we only consider the top 300 airports. We do this for two reasons: firstly, we only have reliable data for movements and aircraft types at those airports; Secondly, the movements at these airports tends to be mostly large commercial jet traffic rather than general aviation. Moving beyond the largest 300 means capturing ever larger fractions of small jet and general aviation movements, where the FOD cost per movement is much less than those seen by large commercial aircraft. Restricting our view to the top 300 airports ensures we are making like-for-like comparisons.

[1] The "shower of sparks" can be seen at http://www.youtube.com/watch?v=iU6QG79dw2g. An image of the downed aircraft can be found at http://www.cnn.com/2007/WORLD/meast/03/12/dubai.airport/index.html

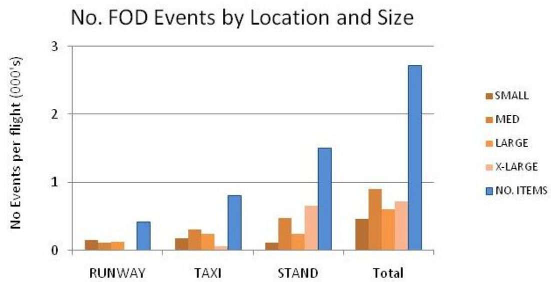
However, this $1.1Bn value is not the end story. If indirect costs are included (based on a multiple of 10x direct costs) the overall value of FOD to airlines at the 300 largest airports rises to $12.4 Bn per year.

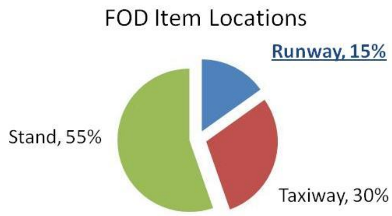
Note that the value to airports is not included in the figure. Airport costs are beyond the scope of this study, and so not included here.

Note: As nice as it is that our data more or less matches Boeing's estimate, we may be indulging in a circular argument. Our figures for cost are based on one airline's estimated expenditure per month. If the airline who gave us the estimate happened to make their estimate by starting with Boeing number and working backwards, then it shouldn't be a surprise that when we work it forward again we come up with the same answer as Boeing. Sadly, the airline's cost estimation method has not been disclosed. For the future, we hope to engage additional airlines and to work through their costs from the bottom-up. This would give us a much more robust picture, and inter- airline comparisons would help us to understand if there are any significant differences in how FOD affects different aircraft types, as well as the extent of damage occurring in different regions. However, until that work is done the numbers presented here are the best available.

'Where is the FOD found?'

There has only ever been one airport-wide study of FOD. This was a survey conducted by the UK's CAA, over ten months during 2004. The survey noted the size, weight, type and location of each item found, and took a picture of the debris.

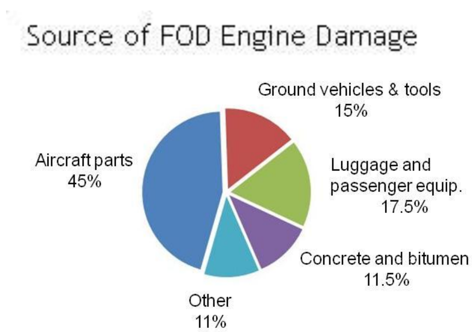




Examination of FOD records at other major European and US airports matches the rough levels and distribution of FOD found in the CAA study, but no other source is as comprehensive.

Is FOD more dangerous on the runway or the ramp?

Delta Airlines commissioned a set of forensic analysis (by FAST, of California) of FOD engine events to determine the composition of the item that caused each FOD event. This gave Delta a breakdown of incidents involving aircraft parts, luggage parts, ground equipment, tools, etc.,.



(source: FOD/Wildlife, An Airline Perspective, Jim Stefan, Delta Air Lines Corporate Safety, April10 2005, Presented at AOA, http://www.aoaexpo.com/2006sessions.html).

Matching Delta's distribution of FOD engine damage sources against the CAA distribution of FOD around the airport, it is possible to estimate which parts of the airport are causing what fraction of the damage. This analysis suggests that even though only 15% of FOD is found on ruways, that

FOD accounts for up to 50% of the damage, with the remainder of damage occurring 40% on taxiways, and only 10% on the stand.

Runways are the most important area to monitor for FOD from a safety perspective. Aircraft speed and engine spin rates mean that FOD ingestion during take-off and landing is more likely to pose a serious threat. By contrast, FOD on the ramp can cause a tremendous amount of damage and inconvenience but incidents here rarely put lives at risk.

Monitoring runways should therefore be the first priority of any FOD prevention effort. New automated detection technologies (e.g. the Tarsier radar system from Qinetiq) help make that possible, where manual inspection regimes currently have difficulty.

Author's comment

To my surprise, this work seems to be a bit of a 'world first' – simply by virtue of pulling together data from both airlines and airports. All that we intended to do at the start was to answer a deceptively simple question: "What is the cost of FOD?"

Only one other answer to this question seems to exist, a report from Boeing, and that document does not detail the frequency or types of FOD incidents. So, despite its imperfections this seems to be a good first cut at answering that question.

The report is another first, in that there seem to be no data sources publicly available on the frequency of FOD events. The insight we have been able to provide comes courtesy of two airlines good enough to share 'inside' information with us. Interestingly, for one of the airlines this was the first time they had looked at FOD from a cost perspective themselves. The results were a bit surprising. In fact, some of the finance team still resist the idea that it could cost so much, even when reading data from their own maintenance records.

However, do not think this report is the be-all / end-all. Anyone reading this (it can be found on www.FODNews.com) should treat the 'results' cautiously. The numbers presented here represent our best guess based on the available data, rather than hard and tested "facts". Hopefully the data will improve over time. We make no guarantees as to accuracy or reliability.

In that vein, I will happily speak with anyone willing to share data and information from either airline or airport perspectives. My contact details can be found below.

For more information, or to discuss this work, please contact us.

Insight SRI is a London based consulting firm, specialising in ventures, new business creation, and strategy. We work at the intersection of new technology and business strategy. Managing Director Iain McCreary is a former physicist from the Los Alamos National Laboratory, USA. He helped to build the UK Aerospace & Defence practice for Accenture, and with that firm wore a number of interim management hats in various industries from telecommunications to oil and gas firms. He founded and was Managing Director of wireless communications start-up HBL Ltd., and served as (reportedly) the youngest Chief Executive of a European Venture Capital firm at Synergis Technologies. He formed Insight SRI in 2002.

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