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A Learning Experience for Support Engineers and ILS Managers - The F35 Aircraft Sustainment Report	**This report should be mandatory reading, not only for all Support Engineers, but for anyone involved in defence procurement, logistics or operations.** **There are many lessons that can be learnt from this programme, unfortunately given the cost, the critical operational role and the international nature of this programme, those lessons will be very hard learnt indeed.**


United States Government Accountability Office
Report to Congressional Committees

GAO

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F-35 AIRCRAFT SUSTAINMENT

DOD Needs to Address Challenges Affecting Readiness and Cost Transparency

The report, by the US Government Accountability Office [GAO] into the F35 Aircraft Sustainability can be found here: https://www.gao.gov/assets/690/687982.pdf

There are many issues worthy of being addressed, but I have limited this article to the following:

1. Availability Performance Metrics
2. The two legged stool - Missing Elements of the Support Solution
3. Support Engineering / ILS and Through Life Cost
4. Support System Resilience

Availability Performance Metrics

Three metrics have been used to date, two availability targets, Air Vehicle Availability [AVA] and Full Mission Capable [FMC] and one subjective measure - Mission Effectiveness [ME] which is a rating given by the pilots after each sortie. I am not qualified to discuss the ME target, save to say that any contractual metric that is based on a subjective assessment has the potential to be highly contentious. I am therefore constraining myself to the AVA and FMC metrics.

The report states "*The contractor does not have full control over the performance outcomes for which it is paid...*".

This is more or less inevitable when we try to Contract for Availability [CfA]; my contention is that it is not possible to contract for availability when dealing with complex, deployable, defence systems. The reason is simple, there are a great many variables that determine availability, and those variables are never in the control of a single organisation.

This does not mean that we shouldn't set availability targets, it means that you cannot use them in a sustainment (support) contract. Consider a fleet of F35 aircraft operating from an aircraft carrier, some spare engines will be carried by a supporting stores ship, (the future Fleet Solid Support [FSS] vessels in the UK). There are two main systems for getting the spare engines from the stores ship to the carrier, either the Heavy Resupply At Sea [HRAS] rigs or Vertrep, using either helicopters (Merlin, Chinook) or the V22 Osprey. If these systems fail, or if the stores ship is sunk by enemy action, this will impact both the AVA and the FMC targets, but the contractor, Lockheed Martin in this case, can hardly be held responsible for that. A Contractor cannot be held responsible for extended, or contended, Lines of Communication. Other, less extreme examples are included in the report. The upshot is that determining responsibility for performance when applying CfA can be difficult and contentious.

This issue is not confined to the F35 however, it is fairly common. One reaction is to give ever greater responsibility to the Prime Contractor, in an attempt to give them full, or at least greater, control over availability; this may be feasible under peacetime conditions, but it will rarely so when we are on a war footing.

The reality is that we cannot "*Contract for Availability*", what we should contract for is: "*Those elements of support that the Contractor is responsible for, and in control of, that contribute to the achievement of Availability*".

Which doesn't flow off the tongue so easily though. Such an approach is perfectly feasible, but it presupposes the following:

1. That we have a comprehensive definition of the "Support System" and the roles of each stakeholder organisation in that system.
2. That appropriate metrics can and have been applied to each role. Noting that the Key Performance Metrics [KPIs] and Performance Metrics [PIs] will typically apply to the interfaces between organisations - interfaces where something passes from one organisation to another, this could be a physical item, (a spare or a piece of test equipment), information, or responsibility - a Support System Interface Definition should be created which defines the associated metrics and performance targets.
3. That the mechanism for making the measurements is unambiguously defined. i.e. we define how the data is collected, using what software, how is it normalised, how data is 'sentenced', how calculations are performed, etc.
4. That the dependencies between the roles are understood, and there will be inter-dependencies. Performance Metric should be applied to the customer as well as to the contractor/s.
5. That we understand how all the many aspects of support (all the KPI's and PIs) interact to deliver system availability, that we understand the contribution of each metric. (System models have a role here).
6. That we understand how the operational environment, the "Employment Plan", impacts both the Mission System (in terms of reliability and maintainability) and the Support System.

This issue is therefore readily avoidable; if we prepare a comprehensive definition of our Support System, if we use this as the basis of our Sustainability / Support Contracts, if we carefully define the metrics associated with organisational interfaces, if we understand the support system inter-dependencies, and if we design effective mechanisms, in advance, for collecting the requisite data.

That is, we have to put sufficient effort and investment into "designing", documenting and "testing" the "Support System".

The Two Legged Stool - Missing Elements of the Support Solution

Aspire promotes the application of Systems and Systems Engineering concepts to Support Engineering. We do this because modern Defence capabilities are complex, and Systems Engineering is a methodology designed to facilitate the management of complexity. We do it because Defence capability is delivered by a system, a system comprised, at the top level, of the Mission System, the Support System and the Employment Plan. It is a characteristic of systems that the elements that comprise the system interact with each other, it those interactions that determine Operational Performance and Through Life Cost [TLC].

The fact that the system elements interact also implies that there are dependencies between the elements, i.e. if you remove or change an element, the system may not behave as you expect, as you require.

The downside of this is that even minor elements of the system can have a significant impact on overall system performance. Consider two examples:

1. Imagine a fleet of fast jets with an insufficient stock of tyres. Tyres for fast jets are sophisticated compared with those used on a family car, but they are not the most exciting of technologies, Without those tyres however you have a vast investment in technology that you can't use and hundreds of people standing idle.
2. Many years ago, the Army ran out of optical clusters used in the Lynx Helicopter sight, no optical cluster = no sight, no sight = no anti tank capability.

For the want of a nail...

Now the F35 programme seems to be hell bent on testing this "...for the want of a nail..." principle. Consider, the maintenance plan is based on two levels of maintenance, the report states:

"...Organizational-level maintenance performed by squadron-level personnel, and depot-level maintenance."

But the report then goes on to state:

DOD does not have enough capacity to repair F-35 aircraft parts because the establishment of repair capabilities at the military depots is 6 years behind schedule.

Repair capabilities at the military depots were originally planned to be completed by 2016, but program officials told us that some capabilities have now been delayed until 2022.

Program officials in part attributed these delays to the military services not providing enough funding for depot requirements; however, service officials told us that the program office did not clearly identify some depot requirements in a timely manner necessary for the services to fund those requirements.

The result is that it take an average of 172 days to repair an LRU, this has led to spares shortages, and when combined with other factors, for example a high No Fault Found [NFF] rate the inevitable result is poor operational availability and high TLC.

But does this justify an inflammatory phrase like "hell bent"? Well consider also that at the time the report was written, (October 2017) the DOD had no plans in place to provide the US Navy and Marines the interim support that they require when on operations.

Consider this statement from the report:

" ... in 2009 an Independent Logistics Assessment team recommended, among other things, that DOD develop a program wide integrated master schedule that includes key governmental activities and tasks necessary to establish F-35 logistics capabilities required through full-rate production, but the program did not develop such a tool.

and...

In 2014 the program office identified the need to establish a road map with clear decision points to prepare the F-35 enterprise for long-term sustainment.

Finally, in December 2016 the Under Secretary of Defense for Acquisition, Technology, and Logistics directed the program office to submit an integrated master schedule for the deployment of global F-35 sustainment capabilities by January 2017, which is not yet completed.

This, seemingly wilful, neglect of support is not just the province of the DOD, it is all too common as most experienced ILS Practitioners and Support Engineers will testify. But it is rare to see such issues exposed so publicly and so robustly criticised, but then the impact has never been so stark, so critical to the Defence capabilities, and the Defence budgets, of so many nations.

The reality is that there are many, seemingly innocuous, items and services, which if absent or deficient in anyway, can have a profound impact on operational capability. This is a simple concept, readily demonstrated; it is unfathomable therefore that nation states persist in procuring complex systems without adequate support, that "savings" are made by cutting the facilities, spares, manpower etc.

The reality is that these are not savings, they are merely guaranteeing that the much of the money expended purchasing the Mission Systems has been wasted. If you cannot afford the requisite support, you cannot afford the Mission System.

The point of this article is that none of this is necessary, this is a failing of management, politics perhaps, but it is NOT a technical or a financial issue.

The fix is, in principle, simple; stop procuring Mission Systems (e.g. aircraft) and start procuring capabilities. Those capabilities include all aspects of support, so adopt the systems approach procure a "Total System" comprised of the Mission System, the Support System and the Employment Plan. Require the procuring authorities to define these elements in detail, require them to demonstrate how the elements interact to deliver the requisite capability (modern modelling tools and techniques render this eminently feasible).

Require procuring authorities to demonstrate how the (mandatory) TLC estimates have been derived from these same definitions and their interactions (more modelling).

If they cannot present a "Support System" design and "Employment Plans" whose maturity complements that of the Mission System, send them away until they can.

We would not tolerate he purchase of an aircraft with bits of engine missing or empty spaces in the instrument panel so why tolerate missing or deficient elements of support?

We need to stop procuring two legged stools.

Support Engineering / ILS and Through Life Cost

The relationship between Support Engineering and Through Life Cost [TLC] should be self evident, it is generally recognised that in-service support costs make by far the greater contribution to TLC and, as a result ILS Managers often find themselves responsible for managing TLC analysis and TLC predictions. This make sense, the design of an optimal support solution requires a number of investment appraisals to be made, these appraisals typically have to find the appropriate balance between TLC and some measure of Operational Capability. Such appraisals occur whether a Support Engineer is conducting a design trade-off, spares optimisation, Level of Repair Analysis [LoRA], or building and using a sophisticated simulation that addressees both TLC and Operational Capability.

On the F35 programme it would appear that this relationship has not been recognised, I will not repeat the content of the report beyond summarising, what I considered to be some of the key, and telling, points it raised, i.e:

- ❑ **The sustainment costs are extremely high**, contributing to making this the most expensive weapon system in US history, and that almost certainly means it is the most expensive system ever produced on earth. Now we shouldn't read too much into this, something has to occupy this position and it is likely to be a complex and recent acquisition, but the F35 will cost more than the total costs of several legacy systems, the costs would seem to be excessive, in a large part because they have not been managed.

- **The sustainment cost targets which have been set do not relate to what the clients can actually afford.** The concept of "Cost As an Independent Variable" [CAIV] has been around for many years. The concept is simple in theory, treat cost as you would any other design parameter, such as weight or electrical power and design to a target. This concept can, and should be, extended to TLC. If a formal definition of the Support System is prepared during development, if this is combined with definitions of the Mission System and an Employment Plan then we can have a pretty good stab at estimating TLC and operational factors such as availability; particularly so if we capitalise on the capabilities of modern simulation tools. Such an approach facilities both investment appraisals and making budgetary estimates (which will increase in fidelity over time). So this is unnecessary.
- **There is an ongoing cost reduction programme and a programme to improve Reliability and Maintainability**. On ongoing drive to reduce TLC and to improve the R&M characteristics of the design is laudable, but it is clear that on this occasion that much of this activity should have taken place during the development phase. They have been watching a train crash, but rather than trying to prevent the crash, they waited until it occurred and then mobilised to recover the system. This will of course be very difficult and very expensive, it would have been a lot cheaper and lot easier if it was done during development. You don't need me to point out what should have happened, the real challenge is to understand why this situation occurred, what where the drivers of such behaviour, were they technical, commercial, cultural...?
- **There is a lack of transparency, the customer is struggling to link their costs to the capability delivered**. The response to this is similar to that for the 2nd bullet above, on sustainment cost targets. If you have robust definitions of each element of the system, the Mission System, the Support System, the Employment Plan, then this should not be so much of an issue. The source of the cost should be transparent, and the relationship between those cost and performance, will more evident (the relationship is in truth very complex, so it will never be completely transparent I suspect).

To conclude: the TLC of the F35 is unprecedented, it is unsustainable, it is difficult to justify, the audit trail is flawed. The DODs reactive approach to sustainability has resulted in significant readiness challenges, they are at risk of not being able to leverage the capabilities of the aircraft. In summary, they are in danger of paying an enormous price for capabilities that they cannot use. Many of these issues were avoidable if basic Supportability Engineering principles had been applied; with a little innovation, imagination, and investment the vast majority of the issues would have been avoided.

The F35 programme serves as an object lesson because it is so large, so ambitious, and so critical, and because the GAO is fearless in publishing these reports. But the behaviours exposed in this report the lack of commitment to Support Engineering, the lack of understanding and knowledge, the lack of investment in Support Engineering tools, or in personnel, is evident on many programmes and in many other organisations, few can afford to be complacent.

Support System Resilience

The effective support of the F35 is reliant on IT systems, in particular the "Autonomous Logistics Information System" [ALIS]. But such systems rely on having access to sufficient bandwidth, they, including ALIS are vulnerable to cyber-attack; and ALIS and its ilk will be a target for potential adversaries. What doesn't seem to have been considered however is the impact of more conventional warfare, IT systems generally tend not to be bullet proof, they are subject to random failures, particularly so if deployed into extreme operating environments.

So here is a general question, just how resilient are our Support Systems?

In the case of the F35, are we in danger of, inadvertently, making our combat air capability reliant on a functioning air conditioning system for the IT? Farfetched? Possibly not, one commentator has already remarked the system's susceptibility to high temperatures.

Consider an F35 issue, not addressed in this report, the US Marine Corp received some publicity after using a 3D printer to manufacture a small plastic 'bumper' for an F35 landing gear door, whilst underway on the USS Wasp. (https://www.defense.gov/News/Article/Article/1498121/). The original bumper had worn out, the repair policy was to replace the entire door assembly, this would have taken many weeks there being no spares doors on board. By manufacturing that seemingly innocuous spare an engineer kept an asset worth circa £150,000,000, operational. This story raises some questions, such as, who decided on that repair policy, without this innovation, a critical mission could fail for the want of a part worth a couple of dollars. But no one should be complacent, I have railed against such policies being applied to UK systems in recent years.

The issue is not constrained to the F35, whilst I was planning this post, the following article was posted: http://nationalinterest.org/blog/buzz/germanys-air-force-dying-slow-death-25157. This article comes with a cautionary note given the political nature of the publication, but it is a good illustration of the sort of problems we can face. The article reports that the German Airforce's combat capability is being compromised, because sensor pods on the Typhoon are unserviceable, because they cannot be properly cooled, because a cooling system seal cannot be procured…

Just how many, apparently trivial, resources are there that are absolutely critical to combat effectiveness of our complex systems?

Consider where these resources originate and how they make their way into the theatre of operations, i.e. what are the "Lines of Communication"? Then ask, how many ways are there that an enemy, or a potential enemy, could disrupt such Lines of Communication?

Modern Lines of Communication tend to be "Linear" at their core are Supply Chains running from "Foxhole to Factory"; If we implement a Forward to Depth, 1st to 4th, maintenance policy, if we are dependent on information residing in the home country, then they may be extremely long and extremely vulnerable.

It is relatively easy for an insurgent using low technology weapons to disrupt Supply, but reflect on the potential of a "peer to peer" enemy, a Nation State, in this context and it is clear that we need to design and to implement very resilient Support Solutions.

One general approach would be to translate, in so far as is practicable, Linear Supply Chains into Support Networks.

Nets are more resilient than chains, they have "alternative load paths" any impairment due to enemy interdiction, random failures, a lack of robustness, is therefore more readily by passed; networks have inherent resilience.

We could adopt and adapt a number of extant techniques to support the evaluation of our Support Systems, we could deploy the much under-utilised Damage Mode Effect Analysis [DMEA] approach. We could apply a variant of Event Tree Analysis [ETA] in order to identify the effects pf single, or multiple points of failure or potential interdiction.

New technology may help us to implement a more resilient solution. In a future scenario several deployed units may have a flexible, mobile, additive manufacturing capability. The supply lines would not have to run back to a manufacturer in the UK, Europe, the US etc, for many items they only need to reach back to any unit with the appropriate additive manufacturing capability.

Support System resilience may also be increased by more cross training of service personnel (supported by advanced technical publication/training systems), the use of distributed data, the elimination of special to type software and special to type support equipment, tools, etc and their replacement with generic solutions. The use of commercial mobile devices as the core of highly portable test and data gathering systems for example.

We need to undertake a holistic review of the resilience of our Support Systems.

Aspire: Aspire Consulting Ltd are a private and independent company who have provided expert Supportability Engineering services for over 20 years. Our Support Engineering services, our training and our software have been deployed across the Defence and commercial sectors to optimise the operational performance and through life cost of complex systems.

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