Evaluation of Shimming Options with Applications to JSF

(Preliminary Report)

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Abstract

This report represents the first phase of a study conducted by AAI and directed to investigate various shimming approaches that might be feasible for application within the JSF assembly scheme. The study relies heavily on data and results generated from two cost estimation tools (or models) created specifically for the purpose of producing 'ball park' estimates or projections of the possible assembly costs and weight contributions expected with each respective scenario. Extensive research and investigations into the shimming methods applied to the current F-22 program led to formulation of the 'F-22 Mid-Fuselage Cost Estimation Shimming Model'. Even though there are a few exterior skin panels that receive shim during the manufacturing process, benefits of the F-22 model tend to emphasize principles used during the installation of detail parts and the shimming of understructure frame assemblies. Analysis of results from the F-22 model will be presented detailing the various shimming methods specific to that operation along with three alternative approaches involving extensive use of liquid shims. Some of the information acquired from a recent study investigating four different approaches for shimming of large skin panels has been incorporated into a similar estimating tool which is still in work but has been able to generate some tenative results for estimating the shimming requirements associated with a simulation of the JSF upper wing attachment to the lower fram assembly. A brief analysis from the JSF skin attach spreadsheet tool will be covered and preliminary results from the model will be presented outlining the probable costs and weight requirements associated with the four shimming approaches which were proposed by JSF engineers to address the process of exterior skin attachment as it relates to the ship's OML requirements. Finally, an overall summary and results section follows at the end of the analysis.

Background

One of the most critical aspects involved in the design and manufacturing of transportation vehicles is the problem of ‘taking up slack’ during the installation of each detail part and component. This problem is perhaps more predominant in the fighter aircraft industry than any other where thousands of parts ranging from small 6 inch details to large skin panels 30 or 40 feet long must be precisely positioned and installed within the intended space. Additionally, flushness and mismatching of adjacent exterior panels has become critical in order to satisfy Outer Mold Line (OML) requirements associated with the overall radar signature of stealth aircraft. Design concepts have been practiced with the intent to build the ship from the ‘inside out’ or the ‘outside in’, or perhaps from the ‘bottom up’ which tends to minimize the gaps between joined parts in the lower region of the ship and maximize gaps in the upper portion. ‘Designed in’ gaps up to about 0.060” or 0.070” are generally incorporated into the concept to allow for spacial relief during part stack up and to compensate for tolerance mismatches. Traditionally, common specification guidelines have required that gaps of 0.010” or greater be shimmed with an appropriate material during the assembly phase. Several material forms are utilized for the variety of shimming requirements throughout the design and assembly phases with each intended to accomplish specific end results. The more common material forms used for shimming of aircraft assemblies include:

(1) Solid shim stock comprized of aluminum alloys.
(2) Solid shim stock comprized of titanium alloys.
(3) Peel shim stock comprized of thin aluminum sheets laminated with an adhesive.
(4) Peel shim stock comprized of thin titanium sheets laminated with an adhesive.
(5) Peel shim stock comprized of kapton, fiberglass or graphite fabric layers laminated with an adhesive.
(6) Liquid shim materials consisting of epoxy resins filled with solid particulates (usually aluminum or silica or both) which transform into hard solids upon cure.

Of this list, metal shims made from aluminum and titanium (both solid and peel) and liquid shims clearly make up the majority of shimming scenarios in use throughout the industry and this discussion will focus entirely on these forms. All shim substrates made from aluminum must receive surface treatments to provide galvanic corrosion protection between adjoining materials (treatment rendered by chromate dipping solutions, anodizing and/or primer coatings). On the other hand, the superior corrosion properties of titanium preclude surface treatments and may be used in particular gaps where corrosion is a major concern. In addition to being corrosion resistant, harder and heavier, titanium costs 4 to 5 times as much as aluminum. Most solid metal shims are fabricated on the spot during assembly but some may require special machining to accommodate tapers or non-flat surface conformations (titanium is more difficult to machine than aluminum). Simple, bandsaw cuts along 2 or 3 edges followed by filing and sanding of the edges are usually the only machining operations required for most solid (or peel) shims. Typical trim waste factors run around 20 to 30%. Field Service Reports indicate the primary problems, as few as they are, involve migration of the shim and in the case of aluminum materials, corrosion as well (the Appendix contains examples of these reports).

The use of peel shims may reduce the difficulty of installing shims in some cases because the worker can peel off layers to accommodate shim placement. From a structural point of view, metallic solid or peel shimming between frame members and structural subassemblies is the preferred method. Adjoining flanges containing steps or non-flat surfaces are often filled with liquid shim, but this material has historically been limited almost entirely to gaps of 0.030” or less and forbidden at fuel boundries, until recently. Solid shims are almost twice as costly to install as common liquid shims and they can add significant weight contributions to the aircraft. At present, straight liquid shimming along with combinations of the liquid (to 0.030”) and metal solid or peel shims (of varying thicknesses) accommodates the majority of shimming requirements on most aircraft throughout the industry. As designers have become bolder in an effort to reduce costs and weight and to facilitate OML requirements, limitations on liquid shim applications have lessened and its use along fuel tank perimeters and possibly in gaps up to 0.060” are becoming attractive concepts.

While liquid pastes generally offer greater versatility in gap filling as well as lower labor costs when compared to metal counterparts, their application is hindered by at least a couple of problems. They are quite messy to work with and the work life (time to apply before cure starts) is limited to 1 or 2 hours. In addition, subsequent processing must often be delayed while the material undergoes cure. The common product comes in two part kits containing an epoxy base resin mixture and an amine-type curing agent which are mixed prior to application and begins a gellation process about an hour later. Correct application of the viscous epoxy material is insured by observing the degree of 'squeeze-out' that occurs along the edges after the joint is fastened together. Within the time span of the work life certain tasks must be accomplished which include: time for mixing, application time to the faying surfaces, the time required to install the mating part and all necessary fasteners (every 6 to 10th bolt as specified) and if possible, time to remove the edge squeeze-out, all before gellation starts. Typically, the material is bonded to one face or flange of the joint while the other (perhaps the mating part) is treated beforehand with a release agent to prevent bonding to that surface. Raw material wastes for common liquid shim materials are quite high (> 50%). Additional contributions to the overall waste quantity include squeeze-out removal and clean-up which can easily consume another 50 to 70% producing a final cured yield of about 15 to 25% After cure, disassembly and removal of the release agent, the surface is ready to undergo subsequent processing just as any other faying surface (fastener hole drilling, fay surface sealing, etc…).

Several different liquid shim materials have been qualified for use at LMTAS. The F-16's FMS-1048 and FMS-3070 specifications include products from Dexter Hysol (EA-9317, EA-9394) and Magnolia Plastics (Magnobond 6388 and 6448) all of which have a substantial record of production application and field history with that program. Field Service Reports have indicated a few problems associated with F-16 flap actuators when *broken* pieces of liquid shim have been found migrating out of place (an example of one such FSR is given in the Appendix). The brittle characteristics of aged liquid shim materials appear to be a major concern among some designers. In an effort to relieve the problem, Dexter Hysol recently developed and has been marketing the liquid shim EA-9377 for several years. This material is the primary liquid shim used on the F-22 program (5PTMKT03) and appears to offer compatability benefits not found with other mainstream liquid shim materials. EA-9377 represents the baseline liquid shim covered in this report and will automatically be assumed whenever 'standard liquid shim' is referred to.

While viscous pastes are the most prominent forms of pre-cured liquid shim materials, an alternative form as gained substantial recognition lately. When the two parts are mixed beforehand by the vendor, formed into die cuts, sheets or strips and then frozen, the onset of cure can be postponed until the material is pull out of frozen storage by the user just prior to application. In this scenario, the worker applies a flexible (thawing) film-like material to the flange (faying) area. Being much easier to handle and apply, this precludes many of the messy attributes associated with common liquid shims. The technician must apply the thawing material to the faying surfaces, trim it to fit the edges, punture holes for *all* the fasteners and then fasten the assembly together within a worklife span typical of common epoxy resins. Pre-cut and tapered pieces specially produced by the vendor minimizes material waste and helps control squeeze-out. The pre-catalyzed film/sheet liquid shimming material known as Dynamold DMS-4-828 is presently the only source of this material form and will be considered heavily in this report. In 2000, Dexter Hysol is expected to begin development of a competitive film-like shim material based on EA-9377.

F-22 Mid-Fuselage Cost Estimation Shimming Model

Investigations of the shimming methods used on the LMTAS F-22 component were initiated in late 1998 and have led to this first iteration of cost estimations which tend to characterize several shimming approaches as applied to the F-22 article. Starting with the current F-22 scenario which now allows EA-9377 liquid shim at fuel boundries and perimeters, the model (a spreadsheet-based approximation tool) encompasses a simplified version of the entire shimming operation. During the initial course of investigations, the F-22 program did not allow the use of liquid shim at fuel tank boundries which only involve straight metallic shims (both solid and peel Al and Ti). But this has recently changed and the model has been expanded to reflect a baseline scenario representing the now current F-22 configuration which employs liquid shim to 0.030" throughout the component (straight liquid and liquid/solid combinations, as a consequence, now occupy essentially all of the shimming space). While there are several other materials used for shimming in special joints (polyimide, fiberglass and graphite peel shims, form-in-place laminates, stainless steel, cres), the sum of all of these forms comes out to less than 1% of the total and are omitted from the estimates. Clearly, the use of EA-9377 liquid shim along with shims made from aluminum and titanium metal make up 99% of the overall shimming scenario for the F-22 component. Weight contributions from a given scenario depend on the volume fraction of each material type used since the densities of prominent shimming materials differs considerably (Al: 2.7, Ti: 4.5, EA-9377: 1.5 and Dynamold: 1.6 which is not used on the F-22 but is considered in possible alternative scenarios).

An extensive inventory analysis of all the shimming materials issued for the F-22 LMTAS program throughout the 1998 year provided the basis for establishing specific material usage and costs as well as important insights into numerous physical attributes characteristic of that particular shimming scheme. Evaluation of aluminum shim stock issued during that period produced a distribution curve roughly indicating that approximately half of the shims were used for gaps within the 0.010" to 0.030" range and half for gaps 0.030" to 0.070". In order to encompass critical elements for the cost/weight estimation tool, it became necessary to acquire rough estimates regarding the distribution of shims relative to the total shimming surface area and the total shim volume. These values provided quantitative approximations for each of the respective shim types used in the scenario and led to estimates of the total weight contribution to the aircraft as well as the total material costs. As it turns out, about 40% of the surface area is occupied by straight liquid shim while the remaining portion accommodates primarily *liquid/solid combinations*, however, the fraction of shim volume occupied below the 0.030" gap level (liquid shim) is only about 20% since the larger gaps contain more material. Plots of aluminum shimming area and shim volume at incremental gaps from 0.010" through 0.071" for the F-22 are given in Figures 1 and 2 respectively.

Figure 1. Area of Al shim occupation for the F-22.

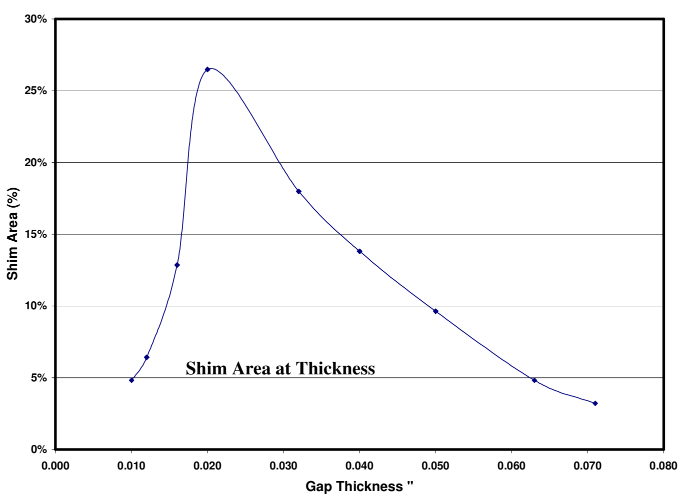
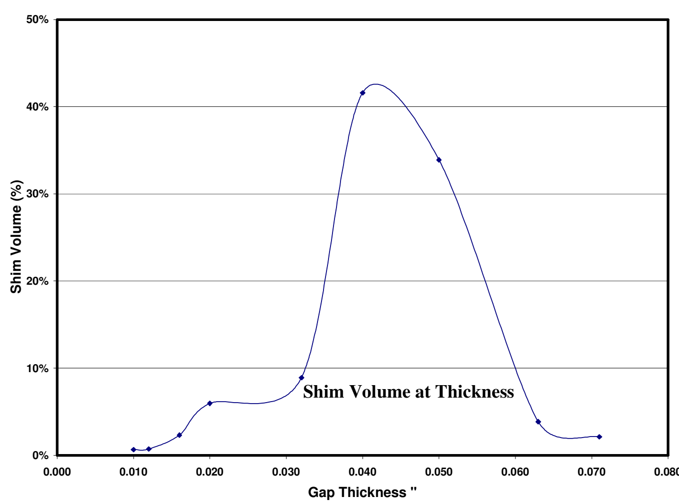


Figure 2. Volume of Al shim occupation for the F-22.



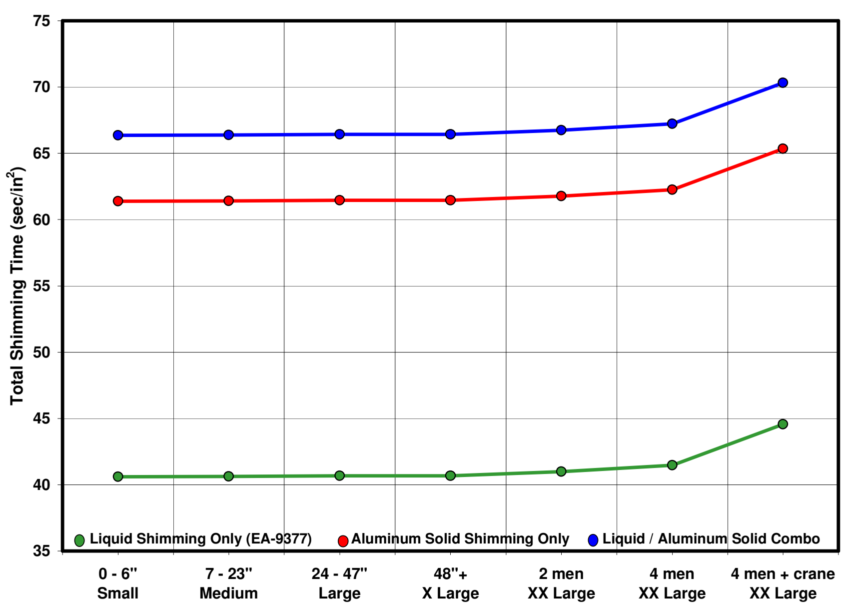
Close communications with F-22 process engineers and application personnel provided invaluable insight regarding specific details associated with the installation of shims as well as general approximations for the quantities of each of the shim types employed for the program. Some of this information has been substantiated by independent estimations derived from within the model. Rough distributions approximately describing the F-22 shimming scheme are shown in Table 1 where an average liquid shim thickness of 0.020" is assumed and the overall gap average is estimated to be 0.0356":

Table 1. Approximate distributions of shims for the F-22 scenario prior to liquid shim use at fuel boundries.

	Weight lbs	Volume in^3	Volume %	Area in^2	Area %	Ave T in
Liquid by itself	8.3	156	21%	7,820	37%	0.0200
Solid Al by itself	5.2	53	7%	1,772	8%	0.0301
Solid Ti by itself	6.9	43	6%	1,257	6%	0.0340
Peel Al by itself	1.8	18.3	2%	441	2%	0.0414
Peel Ti by itself	1.4	8.4	1%	189	1%	0.0447
Liquid + Al solid	16	210	28%	4,652	22%	0.0451
Liquid + Ti solid	20	168	22%	3,427	16%	0.0490
Liquid + Al peel	5.8	72	9%	1,273	6%	0.0564
Liquid + Ti Peel	4.1	33	4%	555	3%	0.0597
	69	762	100%	21,386	100%	**0.0356**

Estimations regarding the application (or labor) time required for shimming operations was derived from established LMTAS 4M time standards in which an abundance of data exists after being accumulated and averaged over several years by the IE department. Detailed process scenerios were constructed for each of the shimming types characteristic of all the specific motions involved in each of the methods and resulted in total application time standards for (1) solid Al, (2) solid Ti, (3) peel Al, (4) peel Ti, (5) straight liquid shim, (6) liquid/solid Al combinations, (7) liquid/solid Ti combinations, (8) liquid/peel Al combinations, and (9) liquid/peel Ti combinations. Each process sequence was comprehensive except for actions associated with the mating part (obtaining, loading, locating, removing, etc…) which was left out in order to determine the effect of mating part size on the total shimming time (small detail vs a large skin panel for instance). As Figure 3 illustrates, mating part size is insignificant until several people are involved and/or a crane is used for part handling.

Figure 3. Effect of mating part size on total shimming time.



It is necessary to further divide and identify any given shimming task with respect to 'confined' and 'unconfined' situations. Confined situations represent tasks limited by access to the specific work area and obviously take up more time than unconfined processes which are not hindered by obstacles or limited access in order to accomplish the required tasks. Since ample 4M data is available for both situations, shimming sequences were constructed for each. After consultations with F-22 personnel, it was decided that overall, about 30% of the shimming processes could be considered as confined and the rest unconfined, so average shimming types for each of the material types was arrived at and incorporated into the spreadsheet model. This permitted a detailed breakdown of the entire F-22 shimming scheme which could be summed up into an overall result reflecting the bottom line as illustrated in Table 2.

Additionally, three alternative shimming concepts were examined and incorporated into the model in order to determine their relative impact on the total cost and weight contribution for each approach.

(1) Use of EA-9377 liquid shim in all gaps from 0.010" (current lower specification limit) to 0.060". The material is applied in the customary fashion from two part Semco injection kits (total catalyzed material in each 6 ounce Semco tube is about 3½ ounces volume). The small amount of shim area from 0.060" to 0.070" is filled with liquid/solid combinations however, a 5% minimum useage of straight metal shim is assumed for situations requiring only solid shim fits (certain hinges and joints).

(2) Use of Dynamold (DMS-4-828) liquid shim applied to all gaps 0.010" to 0.060" the same as scenario (1) above except the DMS material is applied as frozen sheets and strips which begin to thaw after removal from dry ice and are flexible during the application procedure – almost identical to AF-10 adhesive film (Seal Bond). These pieces are tailored by the vendor to roughly fit the faying surfaces so that trimming and waste are minimal. The material is pre-mix by the vendor, formed into the required dimensions and then frozen before shipment to LMTAS. Dynamold's DMS-4-828 frozen liquid shim is roughly 5% heavier than EA-9377 (slightly higher in density). While production phase material costs for pre-cut DMS-4-828 are projected to be higher than EA-9377, raw material waste (20-30%) and trim-off waste during application are expected to be much lower, an attribute that deviates from AF-10 adhesive film where raw material wastes are considerably higher (40-50%).

(3) Even though omitting shim requirements for gaps below 0.020" is probably not structurally sound, the scenario was estimated just to identify any possible benefits that might exist. Again, Dynamold is applied in the same manner as (2) except in gaps lower than 0.020" where nothing but sealant is assumed to be present. The results reveal, as indicated earlier with the volume/gap curve, that very little sealant volume (hence weight and material cost) is associated with the smaller gaps. However, since about 12% of the labor is eliminated (associated with shimming in the 0.010" to 0.020" range), about 10% overall cost savings is indicated. (Note: Labor is computed by surface area while weight and material costs are estimates from volume).

When all the scenarios presented in Table 2 are adjusted for labor PF&D, realization and support as well as material AAF and overhead factors, the final results represent approximate recurring estimates for the the actual (absolute) 'Total Cost' associated with each approach. The current F-22 scheme is represented by the sums of the upper five catagories (five shimming types were considered) given at the bottom of the first section in Table 2, 'F-22 Mid-Fuselage Totals'. In the bottom section of the table, each of the three categories shown describe consolidated results for the three alternative approaches discussed in (1) thru (3) above. For clarity, an enhanced bar chart displaying the results of Table 2 (four scenarios – the F-22 baseline and the three methods above) is given in Figure 3 which follows.

Table 2. Cost estimation model for the current F-22 mid-fuselage shimming approach.

F-22 Model For Projecting Understructure Shimming Costs

F-22 Mid-Fuselage Shimming Scenario (Current Baseline)

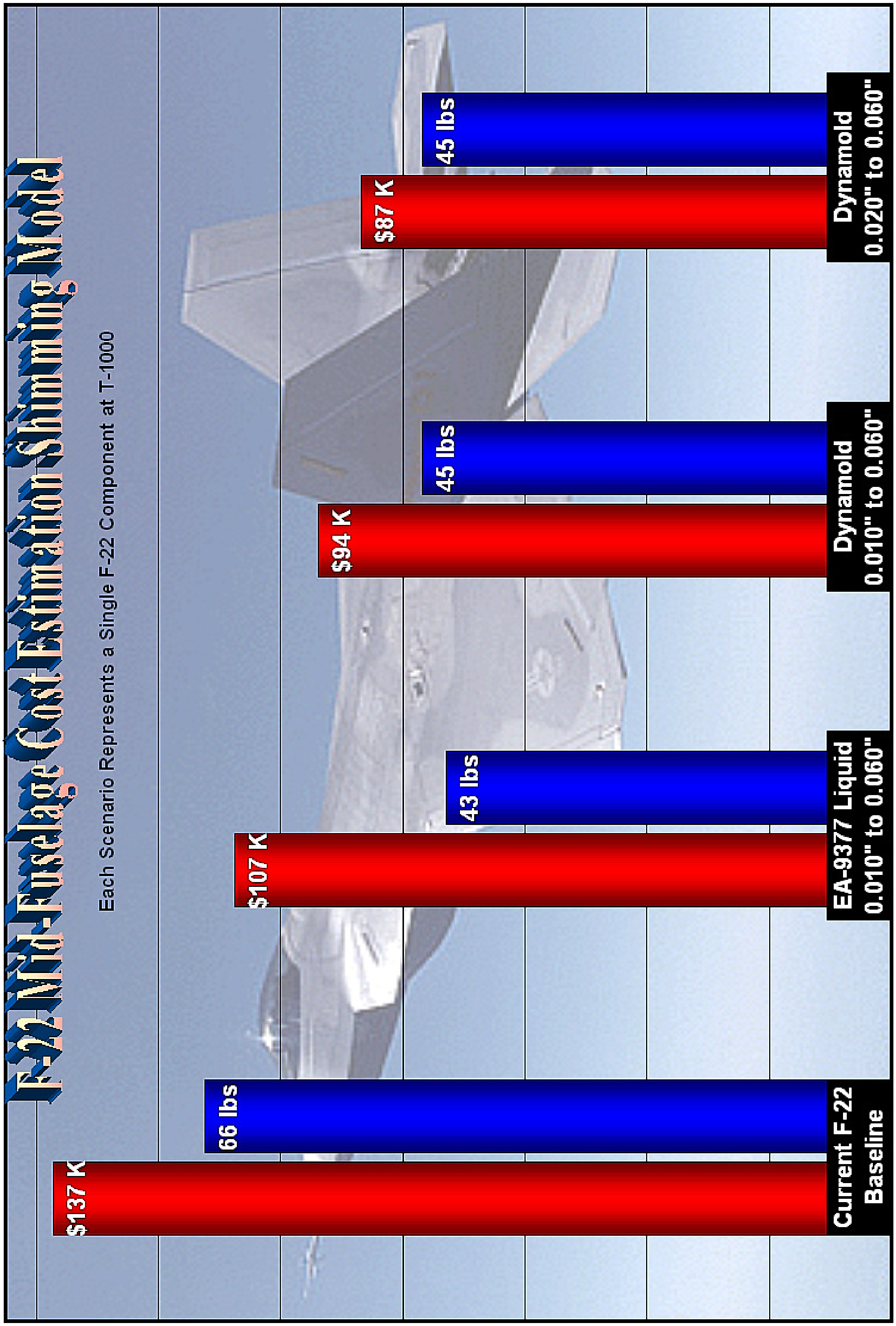
Shim Types		Distribution: Shim Volume	Shim Area	Shim Count	Material Costs: Unit Cost (1)	Total per F-22	Labor Costs: Estimated Touch Labor Hours (2)	Estimated Touch Labor Costs (3)	Estimated Support Labor Costs (4)	Total Cost (5) & Weight: Total Cost Per Component	Total Weight Per Component
Solid Shim Only	Al	2%	3%	2%	$55 per lb. (Aluminum)	$302	27	$2,071	$701	$3,074	1.8
Aluminum and titanium alloy with minimal use in special or critical areas (hinges).	Ti	2%	2%	2%	$265 per lb. (Titanium)	$973	22	$1,701	$576	$3,250	2.3
Liquid Shim Only EA-9377 Aluminum filled epoxy resin in gaps up to 0.030" throughout including fuel boundries.		24%	42%	41%	$138 per lb. (EA-9377) (from 6 oz. tubes)	$10,976	253	$19,298	$6,535	$36,809	9.6
Peel Shim Only	Al	1%	1%	1%	$178 per lb. (Aluminum)	$268	7	$517	$175	$960	0.6
Aluminum and titanium alloy with minimal use in special or critical areas (hinges).	Ti	0%	0%	0%	$436 per lb. (Titanium)	$374	3	$256	$87	$717	0.5
Solid Shim + Liquid Shim	Al	31%	24%	23%		$11,043	249	$19,021	$6,441	$36,505	18
Combinations of EA-9377 (up to 0.030") and Al or Ti in all areas throughout.	Ti	25%	18%	18%		$15,764	204	$15,548	$5,265	$36,577	22
Peel Shim + Liquid Shim	Al	11%	7%	8%		$4,578	68	$5,223	$1,769	$11,569	6.5
Combinations of EA-9377 (up to 0.030") and Al or Ti in all areas throughout.	Ti	5%	3%	4%		$4,252	33	$2,527	$856	$7,634	4.6
		100%	100%	100%							
					F-22 Mid-Fuselage Totals →	$48,529	867	$66,161	$22,405	$137,095	66

(1) Purchase price plus AAF factor 20.6% then material overhead factor 21.0%
(2) Standard hours plus a PF&D factor 15.2% then divide by performance factor 45%
(3) Estimated Touch Labor Hours times $76.34 touch labor cost rate
(4) Estimated Touch Labor Hours times 36% support labor factor then times $71.81 support rate
(5) Sum of Material, Touch Labor and Support Labor Costs

F-22 Mid-Fuselage Shimming Alternatives

Shimming Materials & Methods		Distribution: Shim Volume	Shim Area	Shim Count	Material Costs: Unit Cost (1)	total per F-22	Labor Costs: Estimated Touch Labor Hours (2)	Estimated Touch Labor Costs (3)	Estimated Support Labor Costs (4)	Total Cost (5) & Weight: Total Cost Per Component	Total Weight Per Component
Liquid Shim 0.010" to 0.060"	EA-9377	94%	95%	-----	$138 per lb. (EA-9377)	$45,157					
	Al solid	2%	2%	-----	$55 per lb. (Aluminum)	$164					
Straight liquid shim (EA-9377) used in all gaps	Ti solid	2%	1%	-----	$265 per lb. (Titanium)	$459	600	$45,818	$15,516	$107,405	43
from 0.010" (common lower limit) to 0.060".	Al peel	1%	1%	-----	$178 per lb. (Aluminum)	$129					
Larger gaps use liquid/solid combinations.	Ti peel	0%	0%	-----	$436 per lb. (Titanium)	$162					
						$46,072					
Dynamold 0.010" to 0.060"	Dynamold	94%	95%	-----	$438 per lb. (DMS-4-828)	$35,159					
	Al solid	2%	2%	-----		$164					
Dynamold liquid (frozen) shim used in all gaps	Ti solid	2%	1%	-----		$459	564	$43,072	$14,586	$93,731	45
from 0.010" (common lower limit) to 0.060".	Al peel	1%	1%	-----		$129					
Larger gaps use liquid/solid combinations.	Ti peel	0%	0%	-----		$162					
						$36,074					
Dynamold 0.020" to 0.060"	Dynamold			-----		$35,076					
	Al solid			-----		$161					
Dynamold liquid (frozen) shim used in all gaps	Ti solid			-----		$450	496	$37,902	$12,835	$86,708	45
from 0.020" (adjusted lower limit) to 0.060".	Al peel			-----		$127					
Larger gaps use liquid/solid combinations.	Ti peel			-----		$158					
						$35,972					

Figure 3. Graphical result of F-22 cost estimation shimming spreadsheet with alternatives.



JSF Upper Wing Attachment Shimming Cost Estimations

Recently, a 'Shimming Matrix' was compiled by JSF engineers outlining six different shimming approaches that might be feasible during the application of large exterior skin panels. One of the primary objectives was to examine various methods to attach outer panels in a manner that assists or possibly helps control mismatch conditions along the Outer Mold Line (OML) surfaces. After preliminary reviews and downselect, two of the original 'Shimming Matrix' options were dropped and the current draft now consists of four remaining options. This table is given at the end of the Appendix (the last page of the report). In addition to a common liquid shim approach (the baseline), the study is considering the application of several techniques never before tried such as the use of a new tool for precisely measuring substructure IML to skin OML differences (the Laser Tracker), special tools (perhaps utilizing vacuum) for precisely locating the skin panel to OML, and the addition of sacrificial material to the skin IML (during skin fabrication) for subsequent machining in lieu of hard shimming. Brief descriptions of these four methods are given below:

Option 1: Substructure is located by tool. Standard methods for gap measurement, liquid and solid shimming are employed. Panel is attached and positioned using set-up bolts at a specified torque (common practice). This is considered the baseline method for the study.

Option 2: Substructure is located by tool. Laser Tracker is used to measure substructure IML to panel OML delta and then stops (hard shims) are installed every 10 inches or so. Standard methods for liquid and solid shimming are employed. Panel is torqued to stop points.

Option 3: Substructure is located by tool. Panel is located by tool to OML. Standard methods for gap measurement, liquid and solid shimming are employed. Panel is attached at OML using tool.

Option 4: Substructure is located by tool. Panel has already been fabricated with additional (sacrificial) material on the IML surface (perhaps fiberglass laminate). Sacrificial material is machined to engineering nominal. Standard methods for liquid shimming are employed.

Evaluation of these four options has just recently gotten underway and incorporated into the project scheme. A few preliminary results are included in this section with an emphasis on the cost attributes and relative weight contributions. A spreadsheet-based estimation tool (or model) is now under construction designed to incorporate similar data and produce similar results as the F-22 model covered earlier. For the present (due to time restraints for verification and refinement), some of the time values from the original Shimming Matrix were simply retained in order to generate tenative results for this report, but many values have already been updated and new process sequences for each approach have been developed along with associated material costs and elements for estimating weight contributions. Some of the techniques developed and utilized in the F-22 model have been incorporated here because the principles directly apply and/or for simplicity. Much time has been spent constructing detailed process sequences for total shimming processes as well as for the shimming steps only. These were applied in the F-22 model (discussed earlier) and specific portions were used for the JSF skin attach model. It was felt that some of the time studies previously published regarding shimming procedures were not universally applicable and so it became necessary to derived more comprehensive sequences with enough detail and modularity to be adaptable to most any shimming operation. While some information was simply carried over from the original 'Shimming Matrix' to assist in this preliminary analysis, modified process sequences for the four options discussed in this section have now been constructed. The modified sequences contain numerous updated elements based on 4M micromatic time standards and in some cases, more comprehensive time values (as time has allowed up to this point) and have incorporated the necessary changes to reflect anticipated shim distributions and more relevant total application times. The specific procedures (modified sequences) utilized for the four options outline above in the JSF skin attachmnet model (to be discussed shortly) are given in Figure 4 on pages 11 and 12.

Figure 4. Process sequences for the four shimming concepts involving attachment of the JSF upper wing attachment procedure.

Option 1: Standard Liquid and Dynamold Shimming

Minimum crew required to effect the operation within the 1 hour shim working life:

EA-9377: **11.1 men**   Dynamold: **12.7 men**

Operation		Std Hours	EA-9377 Span	Dynamold Span
General set-up & miscellaneous (all set-up motions & misc actions for entire operation)		10.705	0.969	0.845
Obtain, load and position skin to structure using crane		0.426	0.426	0.426
Match drill pilot holes and deburr (every 10th hole - 10%)		13.887	1.257	1.096
Install set-up bolts (or clecos)		4.490	0.406	0.354
Check gap using epoxy in plastic bag (10%)		13.649	1.235	1.077
Unload and remove skin using crane (remains on crane)		0.226	0.226	0.226
Install Aluminum solid shims to all gaps > 0.030" (~ 60% of area)		67.08	6.071	5.295
Preparations for liquid shim application (obtain, surface prep, release agent, etc…)		3.50	0.316	0.276
Mix and appy liquid shim to all gaps 0.010" to 0.030" (~ 40% of area)	EA-9377	4.83	**0.437**	
Apply, trim to fit Dynamold to gaps 0.010" to 0.030" (~ 40% of area)	Dynamold	6.19		**0.488**
Load and position skin to structure using crane		0.157	**0.157**	**0.157**
Install set-up bolts (or clecos)		4.490	**0.406**	**0.354**
Cure shim (accelerated curing begins about 1 hour after mixing or removal from dry ice)		1	3	3
Unload and remove skin using crane (remains on crane)		0.226	0.226	0.226
Remove cured 'squeeze-out' along edges (only applies to EA-9377)	EA-9377	5.55	0.502	
Other post cure operations (release agent removal, sealant application, shim re-work - 5%)		11.362	1.028	0.897
Load and position skin to structure using crane		0.157	0.157	0.157
Install set-up bolts (or clecos)		4.490	0.406	0.354
Fair OML surfaces (100% - FS 425 & 556)		5	0.452	0.395

Shim Area Distribution:	Solid	Liquid		Total Labor Time	Total Span	
			EA-9377	151.2	17.7	----------
	60%	40%	Dynamold	147.0	----------	15.6

Option 2: Measure Variation with Laser Tracker, Shim to Stops

Minimum crew required to effect the operation within the 1 hour shim working life:

EA-9377: **15.0 men**   Dynamold: **17.7 men**

Operation		Std Hours	EA-9377 Span	Dynamold Span
General set-up & miscellaneous (all set-up motions & misc actions for entire operation)		10.705	0.714	0.605
Measure skin-to-structure variation with Laser Tracker		8	8	8
Make and install Ti shim stops (1" X 2" solid shims every 10 inches - 10% of area)		12.757	1.610	0.721
Obtain, load and position skin to structure using crane		0.426	0.426	0.024
Match drill pilot holes and deburr (every 10th hole)		13.887	0.926	0.785
Unload and remove skin using crane (remains on crane)		0.226	0.226	0.226
Make and install Aluminum solid shims to all gaps > 0.030" (~ 22.5% of area)		24.15	1.610	1.365
Preparations for liquid shim application (obtain, surface prep, release agent, etc…)		5.90	0.393	0.333
Mix and appy liquid shim to all gaps 0.010" to 0.030" (~ 67.5% of area	EA-9377	8.15	**0.543**	
Apply, trim to fit Dynamold to gaps 0.010" to 0.030" (~ 67.5% of area)	Dynamold	10.44		**0.590**
Load and position skin to structure using crane		0.157	**0.157**	**0.157**
Install set-up bolts (or clecos)		4.490	**0.299**	**0.254**
Cure shim (accelerated curing begins about 1 hour after mixing or removal from dry ice)		1	3	3
Unload and remove skin using crane (remains on crane)		0.226	0.226	0.226
Remove cured 'squeeze-out' along edges (only applies to EA-9377)	EA-9377	8.32	0.555	
Other post cure operations (release agent removal, sealant application, shim re-work - 5%)		17.961	1.197	1.015
Load and position skin to structure using crane		0.157	0.157	0.157
Install set-up bolts (or clecos)		4.490	0.299	0.254
Fair OML surfaces (50% - FS 425)		3	0.167	0.141

Shim Area Distribution:	Solid	Liquid		Total Labor Time	Total Span	
			EA-9377	123.5	20.5	----------
	25%	75%	Dynamold	117.5	----------	17.9

Figure 4. (cont.) Process sequences for the four shimming concepts involving attachment of the JSF upper wing attachment procedure.

Option 3: Vacuum Tooling for Skin OML Location

Minimum crew required to effect the operation within the 1 hour shim working life: EA-9377: **13.9 men** Dynamold: **16.3 men**		Std Hours	EA-9377 Span	Dynamold Span
General set-up & miscellaneous (all set-up motions & misc actions for entire operation)		10.705	0.769	0.655
Obtain, load and position skin to structure using locating tool		0.622	0.622	0.622
Check gap using Dynamold in plastic bag (10%)		13.649	0.981	0.835
Match drill pilot holes and deburr (every 10th hole - 10%)		13.887	0.998	0.850
Unload and remove skin (still attached to tool)		0.226	0.226	0.226
Install Aluminum solid shims to all gaps > 0.030" (~ 40% of area)		39.97	2.871	2.446
Preparations for liquid shim application (obtain, surface prep, release agent, etc…)		5.25	0.377	0.321
Mix and appy liquid shim to all gaps 0.010" to 0.030" (~ 60% of area)	EA-9377	7.24	**0.520**	
Apply, trim to fit Dynamold to gaps 0.010" to 0.030" (~ 60% of area)	Dynamold	9.28		**0.568**
Load and position skin to structure using using locating tool		0.157	**0.157**	**0.157**
Install set-up bolts (or clecos)		4.490	**0.323**	**0.275**
Cure shim (accelerated curing)		1	3	3
Unload and remove skin (still attached to tool)		0.226	0.226	0.226
Remove cured 'squeeze-out' along edges (only applies to EA-9377)	EA-9377	6.65	0.478	
Other post cure operations (release agent removal, sealant application, shim re-work - 5%)		15.133	1.087	0.926
Load and position skin to structure using using locating tool		0.157	0.157	0.157
Install set-up bolts (or clecos)		4.490	0.323	0.275
Fair OML surfaces (100% - FS 425 & 556)		5	0.359	0.306
		Total Labor Time	Total Span	
Shim Area Distribution: Solid 40% Liquid 60%	EA-9377	128.9	13.5	----------
	Dynamold	124.2	----------	11.8

Option 4: Fabricate Skin with IML Excess and Machine to Nominal

Minimum crew required to effect the operation within the 1 hour shim working life: EA-9377: **19.7 men** Dynamold: **23.7 men**		Std Hours	EA-9377 Span	Dynamold Span
General set-up & miscellaneous (all set-up motions & misc actions for entire operation)		10.705	0.545	0.452
Formation of additional (sacrificial) 0.060" to skin IML during fabrication		10.28		
Machine sacrificial material (0.060") on skin IML to nominal		5.6		
Obtain, load and position skin to structure using crane		0.426	0.426	0.426
Match drill pilot holes and deburr (every 10th hole - 10%)		13.887	0.707	0.586
Unload and remove skin using crane (remains on crane)		0.226	0.226	0.226
Preparations for liquid shim application (obtain, surface prep, release agent, etc…)		8.74	0.445	0.369
Mix and appy liquid shim to all gaps 0.010" to 0.030" (~ 100% of area)	EA-9377	12.07	**0.614**	
Apply, trim to fit Dynamold to gaps 0.010" to 0.030" (~ 100% of area)	Dynamold	15.46		**0.653**
Load and position skin to structure using using locating tool		0.157	**0.157**	**0.157**
Install set-up bolts (or clecos)		4.490	**0.229**	**0.190**
Cure shim (accelerated curing)		1	3	3
Unload and remove skin (still attached to tool)		0.226	0.226	0.226
Remove cured 'squeeze-out' along edges (only applies to EA-9377)	EA-9377	11.09	0.564	
Other post cure operations (release agent removal, sealant application, shim re-work - 5%)		22.674	1.154	0.958
Load and position skin to structure using using locating tool		0.157	0.157	0.157
Install set-up bolts (or clecos)		4.490	0.229	0.190
Fair OML surfaces (100% - FS 425 & 556)		5	0.254	0.211
		Total Labor Time	Total Span	
Shim Area Distribution: Solid 0% Liquid 100%	EA-9377	111.2	8.9	----------
	Dynamold	103.5	----------	7.8

These sequences deal specifically with the 34 foot JSF upper wing-to-wing carry through skin panel attachment process which will be covered in greater detail in a moment but first, a few points should be clarified regarding certain items within the sequences. In contrast to the original Shimming Matrix, fractions for liquid and solid shimming (based on area) cannot be the same for all four approaches because the gap distance varies as well as the net tolerance for each method. And with a large difference in labor times between liquid and solid shimming, small differences in the expected areal fractions produces significant results. A total area of 10,705 in^2 (vs. 6,000 in^2 for the Matrix) was precisely extrapolated from the Catia drawings as the faying surface area expected to be in contact with the upper wing skin IML and incorporated into these procedures. The minimum crew required to attach the skin panel during the liquid shim's worklife includes: the time for mixing (liquid only), application, trimming (Dynamold only), attaching the panel and installing set-up bolts. This value appears to be undesireably high for most of the options. Removal of pre-cured edge 'squeeze-out' is not possible since access to those surfaces is entirely 'closed-out' after panel installation. Cured squeeze-out must be dealt with after panel removal and probably affects both EA-9377 and Dynamold even though it was figured only into the EA-9377 sequences for this preliminary phase of the study.

Time values for Dynamold were taken from 4M data pools in which ample time standards exist for the application of adhesive films to faying surfaces. Observations have revealed that the techniques for application and trimming of Dynamold are essentially identical to those used daily for faying surface adhesive films at LMTAS. In all likelyhood, these standards, adapted to fit the specifics of Dynamold, are quite adequate (provided the relevant differences are recognized - storing and removal from dry ice, minimal trimming and squeeze-out, room cure, etc..). Additionally, it is felt that comparison and/or integration of 4M time standards (averages refined over many years) with data acquired from one shot videos of processes performed by technicans possibly under pretense may not be entirely proper and perhaps misleading in some cases. Hopefully, these arguments provide at least some justification for the methods that were chosen to represent shimming application times in the current study. In any event, the primary purpose of this section is to present results derived from a recently developed cost estimating tool that examines several shimming scenarios for possible use on JSF during skin panel attachment processes.

An attempt has been made here to develop some first trial results with direct application to the attachment of the JSF 230A-4 upper wing skin panel to the mating frame assembly which forms the Wing Carry Through (WCT) section (see Figure 5). A major concern is the flushness of the outer surface (or OML) of adjacent skin panels that occurs subsequently when the WCT section undergoes mate joint assembly with the forward and aft sections. Shimming at the skin-to-frame interfaces during skin attachment is an attractive method for meeting the prescibed OML dimensions. Since the WCT skin panel concept essentially becomes one of the major close-out panels for the ship, access to the joining regions at certain points during the attachment process will be quite difficult, if not impossible. Therefore, special methods must be contrived in order to satisfy the OML requirements downstream. The four shimming options are intended to address these conditions.

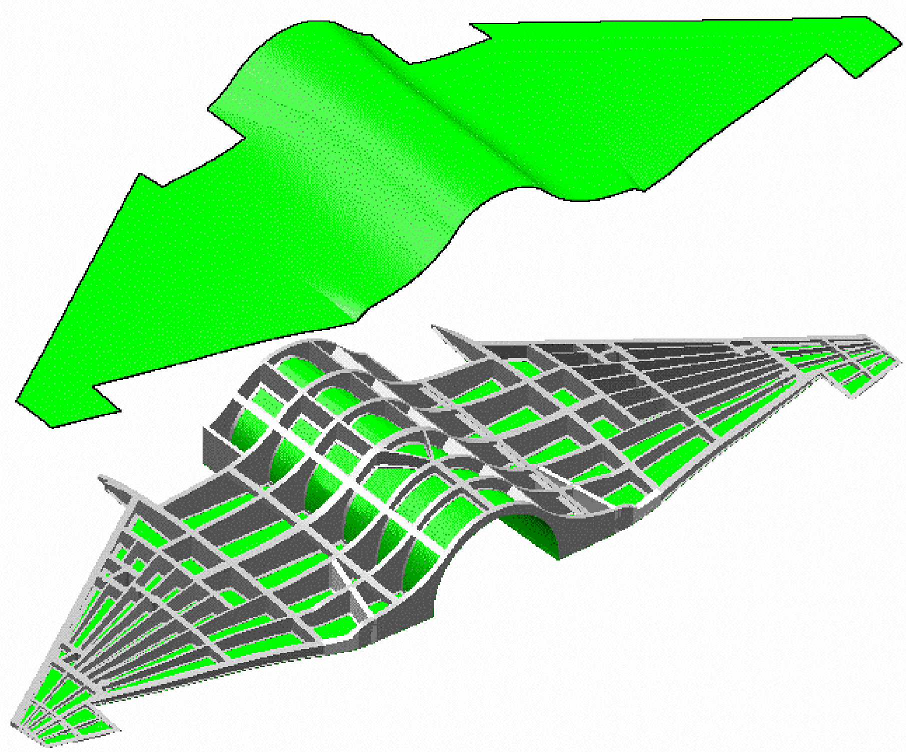


Figure 5. Upper tip-to-tip wing carry through skin panel with mating frame assembly (understructure) shown below.

For simplicity, gaps above 0.030" in all four processes were treated with straight aluminum solid shims rather than liquid/solid combinations which would reduce total costs somewhat but also increase the amount of material that must be applied during the work life of the liquid. Even though Option 1 (common liquid shimming) is considered as the baseline, the extent to which liquid shim is employed here has never been tried before at LMTAS/GDFW (large areas in a single operation and application along the entire upper fuel boundry perimeter). Also, it might be noted that the 'tool located skin - shim to stops' approach appears to offer the only true option for precise OML control (within the tolerance of the locating tool).

Maximum, minimum and overall average gaps between the attached panel and understructure for each scenario were interpolated from the AAI report 'PWSC Baseline Skin Assembly Mismatch' by J. Jacobson. As mentioned earlier, the total flange (faying) area of the upper surface understructure that meets the skin IML was determined to be 10,705 in^2. For simplicity, 100% of the flange area is presumed to contain shims of one form or another. This may not be entirely true for Options 1 and 4 (common liquid shimming and machining of skin IML) since there may be contact or tangent points between skin and structure. However, the 'PWSC Baseline Skin Assembly Mismatch' report indicates that the minimum design gap is greater than 0.010" for Options 2 and 3 (laser tracker/shim to stops and tool located skin) from which shim occupation over 100% of the area is expected (assuming 0.010" as the lower shimming limit). In addition, fill and faring would likely be expected on all four methods with Options 2 and 3 requiring the least amount.

Finally, when all four scenarios are adjusted for labor PF&D, realization and support as well as material AAF and overhead factors, the final results represent approximate recurring estimates for the the expected (absolute) 'Total Cost' associated with each approach as shown in Table 3. For clarity, an enhanced bar chart displaying the results of Table 3 is given in Figure 6 which follows.

Table 3. Cost/weight estimation model for shimming during attachment of the JSF Upper WCT panel.

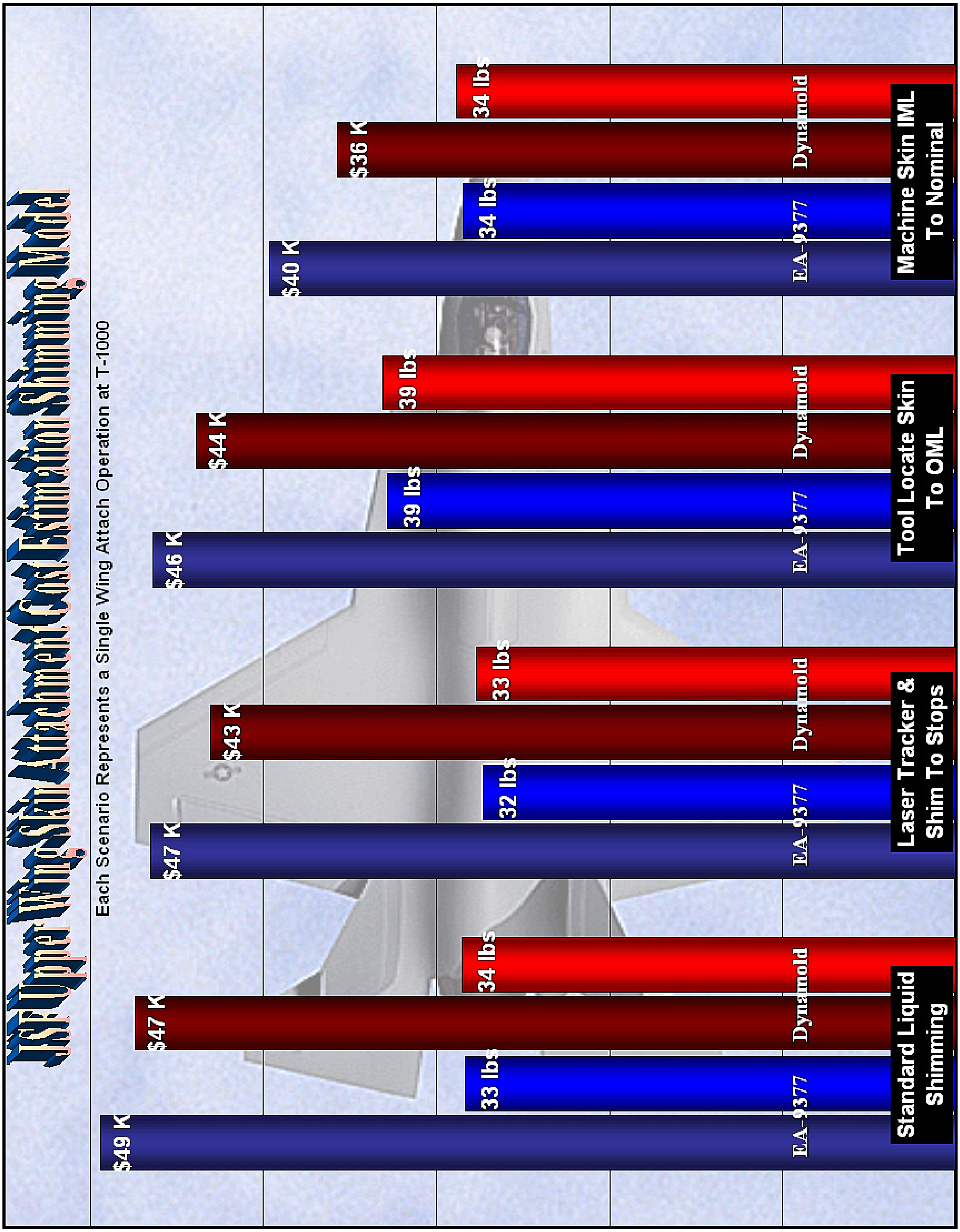
Estimations For JSF 230-A Upper Skin-To-Structure Shimming Costs

Shimming During JSF Wing Carry Through Skin Attachment

Shimming Methods Liquid/Dynamold to 0.030" and Ti solid for gaps > 0.030" in all cases		Shim Distribution: by Volume	Shim Distribution: by Area	Material Costs: Unit Cost (1)		Material Costs: Total per Operation	Labor Costs: Estimated Touch Labor Hours (2)	Labor Costs: Estimated Touch Labor Costs (3)	Labor Costs: Estimated Support Labor Costs (4)	Total Cost (5) & Weight: Total Cost Per Operation	Total Cost (5) & Weight: Weight Contribution Per Operation
Standard Liquid Shimming	EA-9377	20%	40%	$139	per lb.	$9,828	387	$29,553	$10,008	**$49.4 K** (EA-9377)	**33.5 lbs.**
Liquid shimming using common practices and either EA-9377 liquid or Dynamold frozen shim	Al Solid	80%	60%	$55	per lb.						
material. Squeeze-out controlled by set-up bolts.	Dynamold	20%	40%	$438	per lb.	$8,934	376	$28,735	$9,731	**$47.4 K** (Dynamold)	**33.7 lbs.**
Laser Tracker Then Shim To Stops	EA-9377	40%	75%	"		$14,224	316	$24,136	$8,173	**$46.5 K** (EA-9377)	**32.3 lbs.**
Laser Tracker measures variation on skin and structure faying surfaces which permits fab of	Al Solid	60%	25%	"							
shim stops. Squeeze-out controlled by stops.	Dynamold	40%	75%	"		$12,319	301	$22,958	$7,774	**$43.1 K** (Dynamold)	**32.7 lbs.**
Tool Location Of Skin To OML	EA-9377	25%	60%	"		$12,707	330	$25,182	$8,527	**$46.4 K** (EA-9377)	**38.8 lbs.**
Laser Tracker measures variation on skin and structure faying surfaces which permits fab of	Al Solid	75%	40%	"							
shim stops. Squeeze-out controlled by stops.	Dynamold	25%	60%	"		$11,381	318	$24,278	$8,222	**$43.9 K** (Dynamold)	**39.1 lbs.**
Machine Skin IML To Nominal	EA-9377	100%	100%	"		$10,573	285	$21,738	$7,361	**$39.7 K** (EA-9377)	**33.6 lbs.**
Flange (faying) surfaces of skin IML are fabricated with ~0.060" sacrificial material and	Al Solid	0%	0%	"	Includes unsacrificed composite cost					Includes unsacrificed composite weight	
then machined to nominal IML dimensions.	Dynamold	100%	100%	"		$8,667	265	$20,232	$6,851	**$35.8 K** (Dynamold)	**34.1 lbs.**

(1) Purchase price plus AAF factor	20.6%	then material overhead factor	21.0%
(2) Standard hours plus a PF&D factor	15.2%	then divide by performance factor	45%
(3) Estimated Touch Labor Hours times	$76.34	touch labor cost rate	
(4) Estimated Touch Labor Hours times	36%	support labor factor then times	$71.81 support rate
(5) Sum of Material, Touch Labor and Support Labor Costs			

Figure 6. Graphical result of JSF upper skin attach cost estimation shimming approaches.



Summary, Conclusions and Discussion

For this phase of the AAI shimming project, evaluation and analysis of several shimming approaches has focused on tenative results from two spreadsheet-based cost estimation tools. These models are also helpful in generating particular characterizations associated with each scenario and a number of generaliztions as well. Several points can be drawn from the F-22 analysis and, in all likelyhood, have direct implications to other shimming scenaros on other programs. Examination of Table 2 and Figure 3 reveals the obvious differences between the approaches evaluated. However, a detailed summary and more quantitative description of the important points learned from the F-22 study are given below:

(1) Typical shimming scenarios utilizing liquid shim to 0.030” (in all areas) might have close to half the total shim area occupied by straight liquid shim but within less than a quarter of the total shim volume. That is, for an even distribution of shims on either side of the average (or midpoint), most of the volume (and hence weight) would be contained in the larger gaps.

(2) Most traditional shimming programs limited to the ‘less than 0.030” for liquid shim’ limitation use liquid + solid (or peel) combinations for most gaps above 0.030” which helps save costs (less solid shim content, less machining required) and weight.

(3) Total shimming labor time is essentially unaffected by the size of the mating part until the size necessitates the efforts of several workers and/or the use of a crane for handling.

(4) Expansion of liquid shim (EA-9377) use from 0.030” to 0.060” for shimming of details during understructure assembly may provide the following results (as taken from F-22 Table 2):

  (a) Reduction in total touch labor hours of about 30%.

  (b) Reduction in overall costs (material + touch labor + support labor) of about 20%.

  (c) Reduction in shim weight contribution to the aircraft of about 35%.

(5) In a scenario allowing liquid (or Dynamold) shim to 0.060” in all areas, substitution of standard EA-9377 liquid shim entirely to Dynamold (DMS-4-828) pre-catalyzed frozen sheet liquid shim may reduce *total* touch labor hours by about 6% and overall costs by about 15%. However, when only process steps *unique* to each method are compared, touch labor reduction is more on the order of 30% which is about the same value estimated by AAI in early 1999 from the AAD Ballistics Box study. This estimate (30%) is taken from highly detailed step-by-step process sequences specific for each shimming method (mentioned but not included earlier in the report) and should be the value proclaimed during presentations and issued statements comparing the two (for the present, since further examination of the ‘squeeze-out’ removal/cleaning step may affect the difference significantly). Omitting all common steps (surface preparations, release agent application and removal, sealant application, etc…, but for the present, considering shim squeeze-out unique only to EA-9377), comparison between the two methods may be summed up as follows:

Standard Liquid Shim EA-9377		**Dynamold Frozen Shim DMS-4-828**
(obtain, mix, apply, clean [3.73sec/in^2])	minus 30% →	(obtain, apply, trim, puncture)
7.84 sec/in^2	← plus 40%	5.59 sec/in^2

which states that Dynamold takes about 30% less time to apply or EA-9377 takes 40% more time. However, if the time for removal of squeeze-out was considered equivalent for the two (Dynamold may require less removal), then these numbers (taken from 4M data) show that Dynamold would take *more* time to apply than standard liquid shim. Trimming requirements may be reduced by the vendor who can provide more accurate die cuts from templates for a significant material cost increase. Can the step of puncturing (forming) fastener holes in the Dynamold film be eliminated? Simply forcing the bolts through the uncured film is not recommended at this time especially if the effects include formation of voids or defects that must be repaired during the shim re-working step (adding more time to the total). Finally, it is quite possible that, even with accurate sequencing of the all available 4M time standards, more steps may need to be incorporated into the standard liquid shim process to account for additional cleaning tasks not included here due to the the messy, paste consistency of common liquid shim materials. These issues will be refined/resolved in a later report.

(5) The most significant benefits associated with the F-22 study are implied by comparing the two extremes, the current F-22 scenario and the use of Dynamold from 0.020" to 0.060" (omitting shiming in the traditional 0.010"–0.020" range). At the present, this approach is not entirely recommended due to structural implications regarding the use of liquid shim above 0.030" and the lack of *any* shim material below 0.020". Perhaps only structural/design engineers can adequately address these issues. Nevertheless, the benefits of this approach will be pursued here for academic comparisons. While the omission of material in the 0.010"-0.020" range would slightly reduce labor hours (and cost), this study has already shown that relatively small volumes (and weight) of shim material occupy the smaller gaps. On the other hand, replacement of solid shims and liquid/solid combinations by straight liquid in the 0.030"-0.060" range would significantly reduce both labor and material costs as well as weight contribution since the majority of shim material is in the larger gaps. The comparative differences between the current F-22 baseline and Dynamold 0.020" to 0.060" (the last option given in Table 2) are as follows:

(a) Reduction in total touch labor hours of about 45%.

(b) Reduction in overall costs (material + touch labor + support labor) of about 35%.

(c) Reduction in shim weight contribution to the aircraft of about 30%.

At this phase of the project, considerably more time has been spent exploring the F-22 shimming concept model than the JSF upper wing skin attach scenario. As mentioned earlier, the use of straight aluminum solid shims above 0.030" rather than the customary liquid/solid combinations was utilized in all four approaches because of simplicity and a necessary reduction in the areal quantity of liquid shim being applied due to work life concerns. Examination of Table 3 and Figure 6 reveals the obvious qualitative differences between the approaches evaluated. Keeping in mind that the results will likely vary between now and conclusion of the project due to further refinement and corrections, a preliminary description of the important points learned from the JSF study are given below:

(1) Due to work life limitations of both liquid shim materials (EA-9377 liquid paste and DMS-4-828 frozen film), the number of workers required to apply the material and temporaily install the 34' wing panel before the material begins to gel is highly undesirable. Additionally, the time required for ambient cure of either material causes significant delays in subsequent processing (4 hours drill time, 8 hours complete cure). The recommendation here is to pursue vendor assisted development of the epoxy-based materials in an effort to extend the work life of the material(s) beyond the 1 hour limitation and to effect an appropriate cure method (application of energy) which will reduce the cure time to more feasible levels. Studies specifically directed at resolving these conflicts are planned for 2000.

(2) As the data indicates, Option 4, the build-up of sacrificial composite material to the skin IML during the fabrication phase followed by machining to nominal engineering dimensions, seems to provide the lowest cost approach, but also requires the greatest number of simultaneous workers. The necessary composite material (probably fiberglass prepreg) can simply be applied during panel lay-up requiring little or no additional processing materials (bagging, release, canvas, etc…). Option 1 is treated as the baseline approach where both EA-9377 and Dynamold are considered 'standard' for this part of the study (specific breakdowns for each material are given throughout). While both the fabrication process and machining step will require further investigation to either refine or alter these results, the expected benefits associated with the use of Dynamold in Option 4 relative to Option 1 at this point in the study are as follows:

(a) Reduction in total touch labor hours of about 30%.

(b) Reduction in overall costs (material + touch labor + support labor) of about 25%.

(c) Reduction in shim weight contribution to the aircraft is negligible.

As with all four cases evaluated, shim weight contribution is dependent upon the total shim volume and the relative volumes of solid aluminum shim vs. liquid shim since both total volume and relative volume fractions vary for each scenario. Composite weight (Option 4) also contributes to the net weight but the density of glass composite is slightly lower than that for either aluminum/silica filled epoxy resins.

This concludes the preliminary 'Evaluation of Shimming Options' report for 1999. The final report (an expansion and refinement of this one) is expected for completion in March 2000.

Appendix

GENERAL DYNAMICS
FORT WORTH DIVISION

F I E L D   S E R V I C E   R E P O R T

PRODUCT SUPPORT DEPARTMENT

REPORT NO: 88-47-0028	**BASE:** LUKE AFRES	**WUC:** 13B99
DATE REC'D: 140688	**TRUE P/N:** 16L105-11, -25	**HOW MAL:** 846
DATE ANS: 150688	**PART S/N:** NA	**W/D:** M
TYPE VER: F16C5C	**A/C-SE S/N:** 86-0210, 0211, 0212	**A/T:** R
REF DES: NA	**A/C-SE TIME:** 300.0	**REPLY:** N
MFG CODE: 81755	**T.O.:** 1F-16C-4-32	**ENCL:** N
SYSTEM: LANDING GEAR	**FIG:** 4 AND 7	**ATTACH:** N
RESP DEPT: P	**INDEX:** 3 AND 22	**DIST:** A
TYPE ANSWER: C	**ENGINEER:** J. D. WALLIS	
REF REPORT: NA	**ENG CODE:** 1AS0	
OPERATOR: JAH	**AUTHOR:** R. H. STEELE (1w33417)	
ITEM: SHIM MIGRATION, MLG		
TC1: M		
TC2:		***DATA CHANGE**

I N F O R M A T I O N   O N L Y

DETAILS:

In an effort to comply with the request contained in the 22 thru 28 April 1988 WAR the following information is provided. During the last three (3) three hundred hour phase inspections the problem with shim migration has been noted, both in the MLG tension strut collar and the MLG drag pin area.

86-0210 had migration of the 16L105-11 shim on the left MLG.

86-0211 had migration of the 16L105-11 shim on the right MLG.

86-0212 had migration of the 16L105-11 shim on both left and right MLGs and there was also migration of the 2006317-3 shim on the left MLG, both upper and lower.

PRODUCT SUPPORT ENGINEERING COMMENTS:

This is the first reported case of shim migration since Product Support Engineering's request in the Weekly Activity Report (April 22-28) that any site experiencing problems with shim migration report the anomaly to GD/FW via the FSR network.

The above report has been reviewed by Product Support Engineering and is distributed for "Information Only". Any questions regarding this report should be directed to the System Engineer at General Dynamics/Fort Worth, Telephone: 817-763-6640.

SIGNED

J. D. Wallis
Logistics Engineer
Product Support Engineering

SIGNED

C. Wood
Logistics Group Engineer
Product Support Engineering

LOCKHEED MARTIN
Tactical Aircraft Systems

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F I E L D   S E R V I C E   R E P O R T
22 CFR 125.4 (b)(5) APPLICABLE

PRODUCT SUPPORT DEPARTMENT

REPORT NO: 99-33-0028	**BASE:** HAGUE	**WUC:** 11CGH
DATE REC'D: 210799	**TRUE P/N:** 16B4812-91	**HOW MAL:** 170
DATE ANS: 230799	**PART S/N:** NA	**W/D:** M
TYPE VER: F16A6D	**A/C-SE S/N:** 88-0006	**A/T:** R
REF DES: NA	**A/C-SE TIME:** 1802.0	**REPLY:** Y
MFG CODE: 81755	**T.O.:** 1F-16AM-4-51	**ENCL:** N
SYSTEM: INLET	**FIG:** 101	**ATTACH:** N
RESP DEPT: P, E	**INDEX:** 192	**DIST:** A
TYPE ANSWER: C	**ENGINEER:** S. A. VANDER KRAATS	
REF REPORT: NA	**ENG CODE:** 13SV	**I-R:** N
OPERATOR: BDH	**AUTHOR:** W. P. CROMIE (1w00853)	

ITEM: REPLACE INLET STRUT LAMINATED SHIMS WITH SOLID ONES
TC1: M
TC2:

*** DATA CHANGE**

R O U T I N E

REFERENCES: AIWS 8211.C2.99.086

DETAILS:

While performing a phase inspection, technicians observed several laminations of the lower heated engine inlet duct strut shims had worked themselves loose, thereby extending above the inlet mold line. Upon removal, it became obvious the reason for the shims' delimitation and extrusion was corrosion.

The P/N 16B4812-91 Fus Sta 164.35 to 243.00 inlet shims are fabricated from laminated P103A062 material. Due to concerns over engine FOD, the customer would like to replace the laminated shims with solid ones fabricated from 2024-T3 stock. The shims would be machined for proper fit and corrosion treated.

QUESTIONS:

1. What is LMTAS's opinion on substituting solid shims fabricated from 2024-T3 stock for the laminated P103A062 ones used in this application?

2. Would another solid material be more appropriate in this application?

ANSWER:(FINAL): **23 July 1999**

The following information is provided in response to the questions in this report:

1. Lockheed Martin Tactical Aircraft Systems (LMTAS) concurs with the RNLAF's request to use solid material shims in place of the existing P103A062 shim, provided the 0.003 +/-0.002 inch gap criteria and other engineering requirements are met/maintained during and after installation.

2. LMTAS recommends that the shims be fabricated from Alclad 2024-T3, T4, or T81 AMS-QQ-A-250/5 with A100 finish (per FPS-3001). These materials are least likely to experience wear between aluminum mating parts.

SIGNED

S. A. Vander Kraats
F-16 Forward Fuselage/Canopy
Product Support Engineering

SIGNED

R. J. Weiser
Chief
Product Support Engineering

GENERAL DYNAMICS
FORT WORTH DIVISION

F I E L D   S E R V I C E   R E P O R T

PRODUCT SUPPORT DEPARTMENT

REPORT NO: 88-47-0015	**BASE:** LUKE AFRES	**WUC:** 14D00
DATE REC'D: 100388	**TRUE P/N:** 16W011-( ) *	**HOW MAL:** 843
DATE ANS: 110388	**PART S/N:** NA	**W/D:** M
TYPE VER: F16C5C	**A/C-SE S/N:** 86-0252	**A/T:** G
REF DES: NA	**A/C-SE TIME:** 150.0	**REPLY:** N
MFG CODE: 81755	**T.O.:** 1F-16C-2-27JG-80-1	**ENCL:** N
SYSTEM: FLIGHT CONTROLS	**FIG:** NA	**ATTACH:** N
RESP DEPT: P	**INDEX:** NA	**DIST:** A
TYPE ANSWER: C	**ENGINEER:** J. M. MCDONALD	
REF REPORT: NA	**ENG CODE:** 1DN4	
OPERATOR: JAH	**AUTHOR:** M. O. ROBERTS (MOR1)	

ITEM: LIQUID SHIM INSTALLATION (LEF ROTARY ACTUATOR)
TC1: N (FSR 88-47-0010)
TC2: 1 ***DATA CHANGE**

I N F O R M A T I O N   O N L Y

DETAILS:

While performing a 150 hour inspection on aircraft 86-0252, a 0.025 inch piece of liquid shim material was discovered migrating from the left No. 1 Leading Edge Flap (LEF) rotary actuator mounting point (lower outboard foot, wing side). Rotary actuator mounting bolts on the wing-side were tight, but loose on the flap-side. Grip length on all bolts were found to be correct. Solid shim material will be used on the new installation.

PRODUCT SUPPORT ENGINEERING COMMENTS:

REFERENCES: (1) FSR 88-47-0010, WUC 14D00
(2) FSR 88-16-0007, WUC 14D00

Reference 1 is a previous report which documents four of the six aircraft which required re-torque of some rotary actuator mounting bolts at the first 150 hour phase inspection. All actuators were installed with liquid shim.

Reference 2 is a previous report of one aircraft (with metal shim) which required re-torque of 3/4 of the rotary actuator mounting bolts.

The above report has been reviewed by Product Support Engineering and is distributed for "Information Only". Any questions regarding this report should be directed to the System Engineer at General Dynamics/Fort Worth, Telephone: 817-763-6645.

SIGNED

J. M. McDonald
Logistics Engineer
Product Support Engineering

SIGNED

C. Wood
Logistics Group Engineer
Product Support Engineering

Shimming Matrix

C-1: U/S Tool Locate, Skin to OML, Squeeze Liquid Shim W/Clecos	Standard Hours	Span	C-2: U/S Tool Locate, Skin to OML, Squeeze Liquid Shim to Stops	Standard Hours	Span	C-3: U/S Tool Locate, Skin to OML, Hold U/S - Locate Skin to OML	Standard Hours	Span	M-5: U/S Tool Locate, Skin Mach IML	Standard Hours
Fab Skin to OML			Fab Skin to OML			Fab Skin to OML			Fab Skin to OML + Sac(060)	10.2841
									Machine Skin IML to Nom.	5.6
Tool Locate Substruct			Tool Locate Substruct			Tool Locate Substruct			Substruct tool Located	
Loc Skn to Struct	0.3756	0.3756				Tool Loc Skn to OML	0.6221	0.6221	Loc Skn to Struct	0.3756
			Measure Variation Skin-U/S	8	8					
			Install Shim Stops	1.3	0.325					
			Apply Hard Shim A/R	8.32	2.08					
			Loc Skn to Struct	0.3756	0.3756					
Instl Set up Bolts	1.4	0.35								
Gap Check (RTV)	5.22	1.305				Gap Check (RTV)	5.22	1.305		
Mtch Dr Pilot Holes	3.5	0.875	Mtch Dr Pilot Holes	3.5	0.875	Mtch Dr Pilot Holes	3.5	0.875	Mtch Dr Pilot Holes	3.5
Remove Skin	0.3756	0.3756	Remove Skin	0.3756	0.3756	Remove Skin	0.2465	0.2465	Remove Skin	0.3756
Apply Hard Shim A/R	8.32	2.08				Apply Hard Shim A/R	8.32	2.08		
Apply Liq Shim	5.1	1.02	Apply Liq Shim	5.1	1.02	Apply Liq Shim	5.1	1.02	Apply Liq Shim	5.1
Relocate Skin	0.3756	0.3756	Relocate Skin	0.3756	0.3756	Relocate Skin	0.3756	0.3756	Relocate Skin	0.3756
Instl Set up Bolts	1.4	0.35	Instl Set up Bolts	1.4	0.35	Instl Set up Bolts	1.4	0.35	Instl Set up Bolts	1.4
Cure Shim	8	8	Cure Shim	8	8	Cure Shim	8	8	Cure Shim	8
									Remove Tool	0.3756
									Retorque Set-up bolts	0.7
Drill / C'Sink			Drill / C'Sink			Drill / C'Sink			Drill / C'Sink	
Remove Skin			Remove Skin			Remove Skin			Remove Skin	
Deburr & Clean			Deburr & Clean			Deburr & Clean			Deburr & Clean	
Apply Sealant			Apply Sealant			Apply Sealant			Apply Sealant	
Relocate Skins			Relocate Skins			Relocate Skins			Relocate Skins	
Install Fasteners			Install Fasteners			Install Fasteners			Install Fasteners	
Fill			Fill			Fill			Fill	
Fair	5	1.25							Fair	5
Total	**39.0668**		**Total**	**36.7468**		**Total**	**32.7842**		**Total**	**41.0865**
Labor Hour Totals(Std.)	**31.0668**		**Labor Hour Totals**	**28.7468**		**Labor Hour Totals**	**24.7842**		**Labor Hour Totals**	**33.0865**
Assembly Labor Hour	**31.0668**		**Assembly Labor Hour**	**28.7468**		**Assembly Labor Hour**	**24.7842**		**Assembly Labor Hour**	**17.2024**
Tools	**0**		**Tools**	**0**		**Tools**	**417**		**Tools**	**0**
Capital	**0**		**Capital**	**83**		**Capital**	**0**		**Capital**	**1333**
Assembly Span		**16.3568**			**21.7768**			**14.8742**		
Labor Hour Totals(Real)	**78.599004**		**Labor Hour Totals(Real)**	**72.729404**		**Labor Hour Totals(Real)**	**62.704026**		**Labor Hour Totals(Real)**	**78.3888**
Real Labor Dollars	**5518.44**		**Real Labor Dollars**	**5106.33**		**Real Labor Dollars**	**4402.45**		**Real Labor Dollars**	**5503.68**
Support Labor Hours	**17.37**		**Support Labor Hours**	**16.07**		**Support Labor Hours**	**13.86**		**Support Labor Hours**	**17.32**
Support Labor Dollars	**1175.45**		**Support Labor Dollars**	**1087.67**		**Support Labor Dollars**	**937.74**		**Support Labor Dollars**	**1172.31**
Total Dollars	**6693.89**		**Total Dollars**	**6277.00**		**Total Dollars**	**5757.19**		**Total Dollars**	**8008.99**
Total Reocurring Dollars	**6693.89**		**Total Reocurring Dollars**	**6194.00**		**Total Reocurring Dollars**	**5340.19**		**Total Reocurring Dollars**	**6675.99**
Assume 2000 Fasteners										
Assume: 10 % Set-Up Bolts										
Assume Dynamold Shim										
Assume 2000 linear Inches w/ Cap width of 3" = 6000 sqin										
Assume Auto Drill										
Assume Hard Shim is Required on 15% of Total 6000 sqin = 900 sqin 1pc = 3"x6" = 18 insq										
Assume IML Surfaces are Ruled										
Assume Sacrifical Plies are Carbon										
Assume 0.03 min / sqin of surface for machining shim										
Assume 30" / min to machine skin with 5 passes / cap width & single pass										
Assume skin is machined when trimmed no added set up										
Assume structure does not move to the machine										
Assume Sacrificial plies = 16 % of 0.250 skin + 0.10" for cleanup = 0.050"										
Assum 0.030" variation in substructure										