Processed Text

advanced composite structural concept material technology primary aircraft structure c anthony jackson lockheed aeronautical system company summary structural weight saving using advanced composite demonstrated many year military aircraft today use material extensively europe taken lead use commercial aircraft primary structure major inhibiter use advanced composite united state cost material cost high remain high relative aluminum key therefore lie significant reduction fabrication assembly cost largest cost structure today assembly part nasa advanced composite technology program lockheed aeronautical system company contract explore develop advanced structural manufacturing concept using advanced composite transport aircraft wing fuselage concept related trade study discussed concept intended lower cost weight use innovative material form process structural configuration minimization part approach trade study downselect primary wing fuselage concept detailed expectation development concept reviewed introduction lockheed program consists two phase phase 1 currently underway phase 2 option scheduled start 1992 phase 1 consists five task task 1 design manufacturing concept assessment subject paper task 2 structural response failure analysis involves structural analysis method development task 3 advanced material concept cover development new polymeric matrix system hsct task 4 assessment review phase final review leading decision whether exercise option phase 2 task 5 box beam subject another paper conference involves fabrication assembly c 130 wing center box developed previous nasa contract goal program identify emerging technology lead 25 percent cost saving 40 50 percent weight saving 50 percent reduction part count validate low cost manufacturing verify structural response weight saving approach four wing three fuselage concept selected program concept shown figure 1 concept selected based potential meeting criterion moderate risk lockheed l 1011 selected prkedhvg page blank filmed resin transfer molded wlng design automatic tow placement wlng design cocured rib caps1 altachment shear tie shear tie braided wing design modular wingbox design integral spar cap integral spar cobonded rib cap integral hat entirely stiffener braided 0 fiber skin laminate structure cap figure la wing conceptssandwich fuselage design inner pan braided stiffener overwrap woven knllted preform frame atachment integrally molded iangular tube braided hat stiffened fuselage design outer fuselage sandwich pultruded roll framed cocured coconsolidated panel one piece braided structure formed hat stiffener tape layed skin figure lb fuselage conceptsthe baseline airplane study wing location selected relatively highly loaded w l l yield test panel tested existing test machine fixture upper surface buckling critical fuselage location selected similar manner figure 2 show location wing section figure 3 show location fuselage section design criterion wing shown figure 4 fuselage figure 5 wing concept four wing concept selected trade study concept 1 modular wing concept built various component fabricated using different process stiffener pultruded skin automatic tape placed rib press formed spar filament wound concept 112 resin transfer molded wing concept made woven stitched preforms molded two piece concept 113 advanced tow placement wing concept also involves fabrication process cover made automatic tow placement atp concept 114 braided wing concept fabricated mainly 2d 3d braiding concept modular wing design shown figure 6 cover spar rib fabricated separately assembled conventional method cover blade stiffened stiffener fabricated dry preforms resin infused either b staged fully cured tee section skin fabricated two part inner skin discontinuous stiffener laid automatic tape dispenser cut strip waterjet cutter gerber cutter outer skin laid tool containing stiffener inner skin strip automatic tape dispenser fabrication sequence shown figure 7 lockheed l 1011 tristar wlng top view wlng box fwd 184 spanwise skin splice 192 sect ows 151 1 figure 2 baseline wing study locationlockheed l 1011 tristar fuselage 19 ft 7 4 178 ft 7 5 i1 0 window figure 3 baseline fuselage study location nx 14 000 lbiin nxy 2 000 lbiin 10 38 psi burst p 7 82 psi crushing l eccentricity 1 oh gt min 70 e6 psi upper cover load w 151 00 cover buckling resistant max allowable strain 006 iniin tension 0044 inan compression figure 4 wing design criteria5 condition crown sidewall keel maximum tension lbiin 1307 432 318 maximum compression lbiin 489 705 943 shear lbiin 150 600 300 load f 750 00 skin shear buckling resistant 1g max allowable strain 006 iniin tension 0044 lniln compression figure 5 fuselage design criterion figure 6 modular wing conceptinner skln cap lay stiffener tool e detail j tape lay outer skin figure 7 modular wing fabrication front rear spar fabricated automatic tow placement alterna tives filament winding tape winding spar designed c section wound

pair form rectangular box cut c section cure rib fabricated separate cap web prepreg ply cut gerber cutter stacked formed shape b staged rib cap placed cover fabrication tool along inner skin strip stiffener outer skin laid directly curing tool caul plate placed assembly bagged cured rib web compression molded using either thermosets thermoplastic final assembly achieved using mechanical fastener concept 2 resin transfer molded wing design concept resin transfer molded rtm wing shown figure 8 design call wing box fabricated two half half consists one complete cover part integral front rear spar integral rib cap consequently design mechanical fastener penetrating outer surface wing box would require large woven stitched preforms close stitching would required debulk preforms sufficiently allow assembled rtm tool assembly final molded half would accomplished mechanical fastener spar web mechanical attachment separately molded rib web figure 9 show fabrication approach spar capiweb stiffener stitched cover mechanical cocured rib capishear tie figure 8 rtm wing concept inject resin cover rib box figure 9 rtm wing fabricationthe wing cover assembly w l l weigh approximately 2500 pound largest rtm assembly fabricated today weigh 250 pound design would thus require considerable scale current technology major concern design large number tool part would required stiffener usually normal skin thus giving closed angle would require segmented tool adjacent pair stiffener various location along wing span probably chordwise set vent would required resin escape release trapped air vent would closed progressively resin migrates outward injection port vent closed pressure would maintained via injection port reduce chance entrapped air settling causing void concept i3 advanced tow placement wing design concept advanced tow placement atp wing shown figure 10 design call wing box tow placed cured single mandrel large size wing box however made handling single mandrel major logistical problem consequently design modified fabricate cover spar separately rectangular tube would tape wound mandrel cut two channel section form blade stiffener process allows ply picked dropped add localized reinforcement 0 degree ply stiffener web spar tow placed pair around mandrel alternative approach would incorporate spar cap cover tow place web group fabrication approach shown figure 11 rib would press diaphragm formed concept i4 braided wing design concept braided wing shown figure 12 design call one piece wing box 2d 30 braiding considered physical size wing box considered f within confines current planned braider today largest 2d braider would difficulty braiding 45 degree angle 12k tow one foot diameter mandrel size carrier type braider five foot diameter machine capable braiding l 1011 size wing box would require enormous amount floor air space importantly individual carrier could dispense high enough quantity fiber make process automatable carrier would require frequent replacement process feasible foreseeable future also partly true 3d braiding limitation closed section tubular structure le severe atlantic research developed automated 3d braider utilizes 9216 fiber carrier fabrication approach shown figure 13 problem fabricating complete wing box concept dropped consideration braiding process retained option smaller assembly part modular wing box concept integral spar cap cap shear tie figure 10 atp wing concept atp channel tape lay spar tape lay outer skin diaphragm form ri figure 11 atp wing fabricationintegral spar cap iinntteeggrraall ssppaarr webkap rib cap integral hat stiffener braided wwiltthh 00 ffiibbeerrss structure iinn ccaapp figure 12 braided wing concept figure 13 braided wing fabricationfuselage concept three fuselage concept selected trade study concept i1 sandwich design incorporating braided triangular tube sandwich concept i2 geodesic design based isogrid concept concept 3 hat stiffened shell design concept i1 sandwich stiffened shell design concept sandwich shell shown figure 14 design consists sandwich using braided triangular tube core tube oriented longitudinally periodically flanged tube shown figure 15 act longerons fabrication approach braid tube using dry fiber pultrude resin bath b stage fly away foam mandrel would required approach tube fully cured assembled using adhesive would eliminate need foam mandrel would create many bond line would difficult inspect inner skin built c section could also pultruded outer skin formed overwrapping tow tape fabrication plan complete barrel section shown figure 16 curved frame member longeron cutaway fastener access inner panel channel section channel section braided triangular tube flanged tube l outer skin figure 14 sandwich stiffened shell conceptfigure 15 flanged triangular tube section pultrude braided triangle filament win assemble detail pultrude inner skin pull form frame figure 16 sandwich fuselage fabricationconcept 112 geodesic fuselage design concept geodesic fuselage shown figure 17 design call isogrid stiffened shell helical stiffener formed winding filcoat material alternately direction filcoat patented lockheed designed material consisting gr ep tape coated equal thickness epoxy filled glass micro balloon called syntactic intersection syntactic squeezed figure 18

show schematic intersection fiber direction continuous intersection height stiffener hoop stiffener continuous pull formed cut individual length intersection clip overwraps stitched dry fiber form containing mainly 245 degree 90 degree ply provide shear flange bending strength clip overwraps combined minimize part resin transfer molded b staged skin finally tape tow wrapped mandrel fabrication process shown figure 19 concept 113 hat stiffened shell fuselage design concept hat stiffened shell fuselage shown figure 20 design consists pultruded hat stiffener cocured advance tow placed skin frame designed resin infusion molded complete assembly cocured alternative fabrication method stiffener braid prior pultrusion fabrication process illustrated figure 21 resin infused intersection clip 3 woven fl3er form geodesic fuselage stiffener mandrel tool cover hoop stiffener segment figure 17 geodesic fuselage conceptlow density syntactic discontinues node unidirectional gwep cont inues node figure 18 geodesic intersection figure 19 geodesic fuselage fabricationdesign feature hat stiffened increase spacing stiffener co cured assy good damage tolerance rfi frame pultruded hat stiffener figure 20 stiffened fuselage shell concept pultrude stiffener frame assemble detail cocure assembly figure 21 stiffened shell fuselage fabricationthe effective way fabricate panel quarter panel essentially upper lower side panel would required use closed hat stiffener lower keel section need studied problem associated entrapment bilge fluid considered major problem composite corrode drainage must however provided prevent accumulation fluid bacteria growth well additional weight trade study figure 22 show summary option considered trade study blade jay hat stiffener considered option wing skin stiffening jay stiffener eliminated difficult fabricate blade show significant enough weight saving justify higher cost hat stiffener posed several problem fuel tank trap fuel provide leak path wide difficult terminate outboard effectively led use blade stiffener l l wing concept blade configuration however different blade configuration three concept carried completion shown figure 23 atp stiffener built side side channel section modular wing stiffener pultruded tapered flange buried skin rtm wing stiffener built woven stitched fabric fuselage concept unique stiffener configuration tradeable configuration fabrication method material concept 1 braid atp rtlwrfl pult tip modular wlng rtm wlng atp wlng braided wlng sandwich fuselage geodesic fuselage stiffened shell fuselage figure 22 trade study optionsatp wlng modular wlng rtm wlng figure 23 stiffener comparison fabrication method looked concept summarized figure 22 method selected component already discussed trade study also looked possible use thermoplastic material instead thermosets high cost thermoplastic material today make use subsonic aircraft unlikely inherent toughness thermoplastic material advantage toughened thermosets much cost effective thermoplastic look good press formed rib even frame main disadvantage mixing material mechanical fastener would required assembly thermosets thermoplastic difficult bond together figure 24 show typical thermoplastic material cost today figure 25 show comparison current projected material cost projected price fact become reality thermoplastic may viable candidate future commercial subsonic transport concept evaluation concept evaluated cost weight design technology advancement manufacturing technology advancement producibility damage tolerance inspectabil ity maintainability repair ability concept meet program goal major consideration scoring system used evaluation gave 40 point cost 30 point weight 30 point factor cost score cost goal divided concept cost multiplied 40 weight score weight goal divided concept weight multiplied 30 factor score total point cost weight divided maximum possible score multiplied 30 summarized figure 26 individual score factor shown appendix along rationale 3 2 i00 4 1 0 99 lb 100 1000 lb 1000 lb n unitape commingled towpreg fabric figure 24 thermoplastic material form cost comparison tip commingled tip unitape bmi unitape epoxy fabric epoxy unitape current projected price price figure 25 cost various compositescost 40 point cost score cost goal cost design x 40 weight 30 poieits welgilts score weight goal weight design x 30 ottietl factor 30 point factor score sum poifits design 1 maximum possible point x 30 figure 26 scoring system weight trade weight wing concept based total weight wing box structure per aircraft optimum sizing structure outer wing station 151 1 obtained spanwise variation used based previous wing study additional weight added account landing gear attach fitting engine mount fitting access door weight fuselage concept based sizing upper shell station 750 sizing assumed maximum tension shear maximum compression shear sizing conservatively assumed constant circum ferential location total weight fuselage station 235 983 taken comparison wing box weight shown figure 27 fuselage segment weight figure 28 summary weight trade study shown figure 29 cost trade cost trade based recurring cost although nonrecurring cost considered producibility trade recurring cost based production run 300 ship set rate five per month

labor rate 1995 projected agreed among act program contractor cost workshop material cost assumed 40 lb sensitivity study material cost performed assumed would purchase facility equipment fly buy dependent fabrication method cost analysis program used accem includes material burden support labor quality control learning curve industrial engineering standard comparison wing concept cost shown figure 30 comparison fuselage cost shown figure 31 cost trade study result summarized figure 32 cover rib bulkhead spar baseline modular rtm atp figure 27 wing box weight skinistringers minor frame 9610 lb baseline sandwich geodesic hatstiffened figure 28 fuselage shell weightsfigure 29 weight trade study result assembly cover spar 7 rib cover spar 1 baseline 13 saving 10 baseline 24 saving figure 30 wing concept cost comparisonsskin efl frame stringer 0 assembly bonded assembly 38 baseline 177 baseline 30 saving figure 31 fuselage concept cost comparison concept cost score 1 1 baseline 2 636 425 goal 25 1 977 31 8 wing modular 2 301 918 34 36 1 rtm 2 912 135 27 1 6 1 1 1 1 atp 2 002 760 39 49 baseline 161 704 goal 25 1 21 278 fuselage sandwich 221 985 21 85 hat stiffened 11 2 962 42 95 figure 32 cost trade study resultscost benefit driver concept summarized figure 33 downselect based trade study one wing one fuselage concept selectec concept shown figure 34 35 figure 36 show summary ranking concept advanced tow placement wing hat stiffened shell fuselage design finished clear winner came close 25 percent cost saving target 40 percent weight saving target exceeded 50 percent reduction part count weight saving goal shown reduced 34 percent account resizing 34 percent overall goal bearing mind fact wing would expected larger saving resizing would fuselage volume constraint selected concept shown figure 37 38 original program plan called continuing backup design wing fuselage end phase 1 primary concept however emerged clear winner decided put l l remaining effort developing validating primary concept expectation development selected concept depend minimization mechanical fastener fabrication large component development concept depends minimization discontinuity development analytical method demonstration repeatable process use process control r concept cost benefit cost driver modular efflcent use tool loading wing material aterial cost additional fastener increased assembly rtm stiffener simplicity tool loading wing reduced part count complex tooling minimal mechanical material cost assembly atp use atp equipment handling wing integral spar cap tool loading reduced assembly sandwich use automated high part count fuselage fabrication process assembly material cost geodesic commonality detail high part count fuselage hand placement detail material cost stiffened shell reduced number part complex tooling fuselage cocured frame figure 33 cost benefit cost driversi cover spar ribcap modular wlng box rtm wlng box atp wlng box figure 34 wing box concept geodesic stiffened figure 35 fuselage concepts48 88 stiffened 27 54 42 95 87 99 shell figure 36 downselect summary design feature one piece design spanwise1 c1 iordwise joint integral continuous blade stiffener uppertlower cover wlth integral spar cap fastenersileai path ttirough cover integral rib cap wlth shear clip figure 37 selected wing conceptdesign feature hat stiffened increase spacing stiffener co cured assy good damage tolerance rfi frame pultruded hat stiffener figure 38 selected fuselage concept effect build quality minimize scrap buy concept involve moderate risk approached incremental manner improve chance success neither concept involves nothing approach altern ative path available needed summary conclusion advanced structural material trade study carried four wing three fuselage concept trade study showed advanced tow placement wing concept hat stiffened shell fuselage concept showed excellent potential meeting program goal weight saving close enough goal reasonable chance meeting exceeding goal development refinement wing cost within one percent goal cost fuselage concept exceeds goal effort underway validate design detailed analysis fabrication test appendix design concept techbiology rationale advancement modular conventional assembly method large cocured cover wing 4 assembly represent sligi technology advancement rtm conventional design configuration exception coverispafi wlng 5 integration stitched preform atp conventional design configuration emptiasis large cocured 5 wing assembly meci ianical fastener significatantly reduced sandwich unique design concept ameanable automated fabrication fuselage 8 teci 1niques simplified frame cover attachment geodesic 6 highly efficient damage tolerant design design suitable fuselage automated manufacturing method stiffened shell design concept current state art configuration fuselage allows cocuring structural element 4 technology ccncept advancement rationale manufacturing modular difficult lay rib cap cocuring cover 3 wing stiffener little technology advancement one shot complete rtm wlng half woucd tremendous rtm 9 advancement technology design eliminates many wlng component fastener atp c

channel block assembly form cover atp 7 represents advancement current mettiods co wing curing integral rib cap significant advancement sandwich significant advancement mandrel technology advancement componet location arena many fuselage 7 tube significant advancement pultruded geodesic atp helical stiffener rfi intersection fuselage 7 clip significant advancement pull forming frame extension technology stiffened shell little advancement aside fact 3 fuselage frame cocured appendix inspect copicept ability rationale separate component cafj inspected also require tvlodular 6 extensive post process inspection due coconsolidation wlng bonding preform may inspected mold filling wide range rtm 8 processmethods could used monitoring mold fill wing cure including process model p tow quality size placement must monitored time wlplg 6 depend machine placement monitoring need del eloped sandwich tube could inspected line post process fuselage 5 difficult tube geodesic complex geometry truss intersection 2 fuselage uninspectable high score component may inspected final stiffened stiell fuselage 8 cure process inspection pultruded hat rtm frame easy goemetry j maintain concept rationale ablln modular 6 modular construction facilitates le costly repair wing technology heavy structural damage unrepairable field level leak path eliminated constructcon facilitates le costly rtm 6 repair technology heavy structural damage unrepairable wlng field level atp leak path eliminated repair field level le costly wlng 7 heavy damage induce remove replacement entire structure sandwici 1 composite material eliminate maintainability issue fuselage 8 repair easily done field level geodesic creates repair problem satisfied without fuselage 4 major reconstruction large area reqiures excessive spare repair part inventory stiffened shell 6 repair problem transfering load across damaged area fuselageappendix l cobicept producibllln rationale modular rib cap configuration difficult fabricate expensive 3 wing provision tolerance float limited access interal fast rtm 6 cofjcept high risk ia high pay also wing access problem modular design atp concept le risk rtm design also le pay wing 6 access problem wing concept many piece length small cross section sandwich triangle make mandrel removal difficult inspection bonded fuselage 3 assembly present problem geodesic many part junctiofi clip difficult fa0 fuselage 3 continuous fiber composite complex tooling many part stiffened shell process automated including rtm pultrusion 8 fuselage filament winding durability 1 concept damage rationale tolerance ijodular 3 concern impact damage cause stiffener pull wing away skin drastically reducing mechanical property thickness reinforcement hould prevent stiffener rtm 7 unbond minimize impact damage lower fiber volume still wlng concern would reduce strljctural integrity atp 5 typical current structure wlng thinness facing durabilir concern impact could cause sandwich fuselage 3 seperation triangular tube large region thls could reduce residual property thls configuration highly redundant geooesic 9 standing durability damage tolerance however fuselage high risk critical manufacturing flaw diagonal cross over stiffened shell considered slightly better current structure fuselage 6 elimination fastener hole appendix technology maintainability1 concept advancement produc bil ty inspectaoility total design mfg modular 4 3 3 3 6 6 25 12 5 wlng rtm wing 5 9 6 7 8 6 41 20 5 atp wing 5 7 6 5 6 7 36 18 0 sandwich fuselage 8 7 3 3 5 8 34 17 0 geodesic 6 7 3 9 2 4 31 15 5 fuselage stiffened shell 4 3 8 6 0 6 35 17 5 fuselage

Top Keywords

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