ITRB Spar Domestic Source Final Report

DLA Contract No. SP4701-10-C-0025
Report No.: ITR-ES-0012

Prepared For:
Jeffry R. Adams
ManTech Branch
RDMR-SEM
Building 5400, Rm S-258
5400 Fowler Road
Redstone Arsenal, AL 35898-5270
jeffry.adams@us.army.mil

Period of Performance: 15 December 2010 – 14 December 2012

Dated: 14 December 2012

UNCLASSIFIED

Prepared by:
Bing Han

Cobham Composite Products
10540 Heater Court
San Diego, CA 92121-4111
Phone: (858) 455-1650
Fax: (858) 455-1698/6459

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
14-12-2012

2. REPORT TYPE
FINAL REPORT

3. DATES COVERED *(From - To)*
15 Dec 2010 – 14 Dec 2012

4. TITLE AND SUBTITLE

ITRB SPAR DOMESTIC SOURCE FINAL REPORT

5a. CONTRACT NUMBER
SP4701-10-C-0025

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

BING HAN

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

COBHAM COMPOSITE PRODUCTS
10540 HEATER COURT
SAN DIEGO, CA 92121

8. PERFORMING ORGANIZATION REPORT NUMBER

ITR-ES-0012

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

MANTECH BRANCH
RDMR-SEM
BUILDING 5400, RM S-258
5400 FOWLER ROAD
REDSTONE ARSENAL, AL 35898-5270

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Distribution Statement A: Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT Cobham Composite Products (Cobham) under contract with the Defense Logistics Agency (DLA) conducted a manufacturability study of the Improved Tail Rotor Blade (ITRB) Spar in order to establish a domestic manufacturing source for the spar where none currently exists. This program was managed by the Army ManTech Program Office (ManTech). This final report summarizes this program performed by Cobham which took place from 15 December 2010 to 14 December 2012.

The Apache AH-64D Helicopter currently uses aluminum Tail Rotor Blades (TRB). Boeing-Mesa, along with Program Management (PM) Apache is currently in the process of developing an ITRB for the AH-64D. The scope of the program included structural design, materials selection, manufacturing producibility analysis, tooling design and fabrication, triaxial braid preform development, fabrication and delivery of triaxial braided spar preforms, Resin Transfer Molding (RTM) process development and trials, and delivery of two (2) composite spars and one (1) destructive test spar. In addition, a set of production quality RTM tools was built and delivered. However, midway through the program, the technical requirements were realigned by introducing the Apache ITRB requirements directly into the program by Boeing Mesa. The realignment of ManTech program requirements to the Apache ITRB requirements was important because it resulted in a ManTech program product that is closer to production readiness. However, the Apache ITRB data are ITAR and export controlled. Therefore many details of this project are not reported here.

The program team consisted of Cobham Composite Products (Cobham) as the prime contractor who was responsible for tooling design and fabrication, fabrication process development and fabrication of spars and test samples; G3 who designed the RTM tooling and supported Cobham with RTM process consulting; A&P Technology who was responsible for the development of the triaxially braided composite preform and Boeing Mesa who provided guidance to ITRB requirements.

15. SUBJECT TERMS: Resin Transfer Molding, RTM, Tri axial Braid, Composite Structure, Tail Rotor Blade

16. SECURITY CLASSIFICATION OF: UNCLASSIFIED			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** JOEL ZUIEBACK
a. REPORT	**b. ABSTRACT**	**b. THIS PAGE**		**33**	**19b. TELEPHONE NUMBER** *(include area code)*
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED			858-455-1650

Table of Contents

Table of Tables

Table of Figures

ABSTRACT

Cobham Composite Products (Cobham) under contract with the Defense Logistics Agency (DLA) conducted a manufacturability study of the Improved Tail Rotor Blade (ITRB) Spar in order to establish a domestic manufacturing source for the spar where none currently exists. This program was managed by the Army ManTech Program Office (ManTech). This final report summarizes this program performed by Cobham which took place from 15 December 2010 to 14 December 2012.

The Apache AH-64D Helicopter currently uses aluminum Tail Rotor Blades (TRB). Boeing-Mesa, along with Program Management (PM) Apache is currently in the process of developing an ITRB for the AH-64D. The scope of the program included structural design, materials selection, manufacturing producibility analysis, tooling design and fabrication, triaxial braid preform development, fabrication and delivery of triaxial braided spar preforms, Resin Transfer Molding (RTM) process development and trials, and delivery of two (2) composite spars and one (1) destructive test spar. In addition, a set of production quality RTM tools was built and delivered. However, midway through the program, the technical requirements were realigned by introducing the Apache ITRB requirements directly into the program by Boeing Mesa. The realignment of ManTech program requirements to the Apache ITRB requirements was important because it resulted in a ManTech program product that is closer to production readiness. However, the Apache ITRB data are ITAR and export controlled. Therefore many details of this project are not reported here.

The program team consisted of Cobham Composite Products (Cobham) as the prime contractor who was responsible for tooling design and fabrication, fabrication process development and fabrication of spars and test samples; G3 who designed the RTM tooling and supported Cobham with RTM process consulting; A&P Technology who was responsible for the development of the triaxially braided composite preform and Boeing Mesa who provided guidance to ITRB requirements.

1. SUMMARY

Cobham Composite Products (Cobham) under contract with the Defense Logistics Agency (DLA) conducted a manufacturability study of the Improved Tail Rotor Blade (ITRB) Spar in order to establish a domestic manufacturing source for the spar where none currently exists. This program was managed by the Army ManTech Program Office (ManTech). This final report summarizes this program performed by Cobham which took place from 15 December 2010 to 14 December 2012. The Apache AH-64D Helicopter currently uses aluminum Tail Rotor Blades (TRB). Boeing-Mesa, along with Program Management (PM) Apache is currently in the process of developing an ITRB for the AH-64D. This effort addresses the potential establishment of a U.S. Source to manufacture the composite spar component of the ITRB. The original scope of the program included design, materials selection, manufacturing producibility analysis, tooling design and fabrication, triaxial preform braid development, RTM process development and trials, and delivery of two (2) composite spars. However, midway through the program, the technical requirements were realigned by introducing the Apache ITRB requirements directly into the program by Boeing Mesa. The realignment of ManTech program requirements to the Apache ITRB requirements was important because it resulted in a ManTech program product that is closer to production readiness. However, the Apache ITRB data are ITAR and export controlled. Therefore many details of this project are not reported here.

The program team consisted of Cobham Composite Products (Cobham) as the prime contractor who was responsible for tooling design and fabrication, fabrication process development and fabrication of spars and test samples; G3 who designed the RTM tooling and supported Cobham with RTM process consulting; A&P Technology who was responsible for the development of the triaxially braided composite preform and Boeing Mesa who provided guidance to ITRB requirements.

INTRODUCTION

The Apache AH-64D Helicopter currently uses aluminum Tail Rotor Blades (TRB). Boeing-Mesa, along with Program Management (PM) Apache is currently in the process of developing an ITRB for the AH-64D. Boeing Mesa has identified only an overseas supplier for the replacement of the composite spar portion of the ITRB blade. This effort addressed the potential establishment of a U.S. Source to manufacture the composite spar component of the ITRB.

Cobham, under contract through Defense Logistics Agency (DLA) and managed by the Army ManTech Program Office (ManTech), conducted a study to establish a manufacturing capability for a Domestic Source for the ITRB Spar (ITRB-DS). Cobham conducted a trade study of manufacturing processes and materials. Along with the study report, Cobham designed, developed, fabricated and delivered Resin Transfer Molded (RTM) composite spars using a tri-axially braided fiber preform supplied by A&P Technology, shown conceptually in **Figure 1**. The scope of the program included design, materials selection, manufacturing producibility analysis, tooling design and fabrication, triaxial preform braid development, RTM process development and trials, and delivery of two (2) composite spars. However, midway through the program, the technical requirements were realigned by introducing the Apache ITRB requirements directly into the program by Boeing Mesa. The realignment of ManTech program requirements to the Apache ITRB requirements was important because it resulted in a ManTech program product that is closer to production readiness.

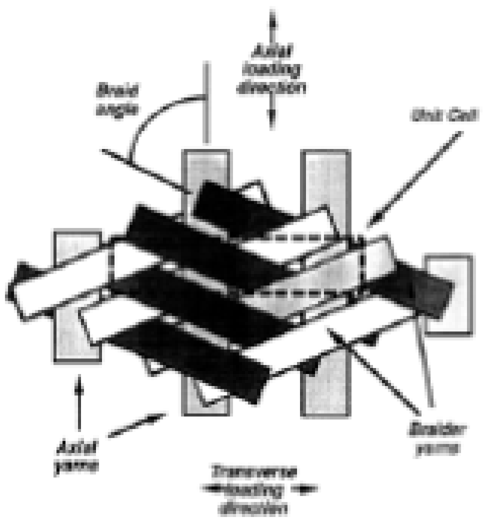


Figure 1 Illustration of Typical Triaxial Braid Architecture

Primary objectives of the Apache ITRB-DS Spar demonstration program include the following:

- Development of a 3-D woven sock preform utilizing changes of inboard section thickness through manipulation of the braid angle.
- Design and fabrication of demonstration tooling, fixtures, Resin Transfer Molding, finish machining and assembly of the development ITRB unit.
- Development of the RTM mold process, with focus on manufacturability and proper resin fill.

2. PROGRAM OVERVIEW

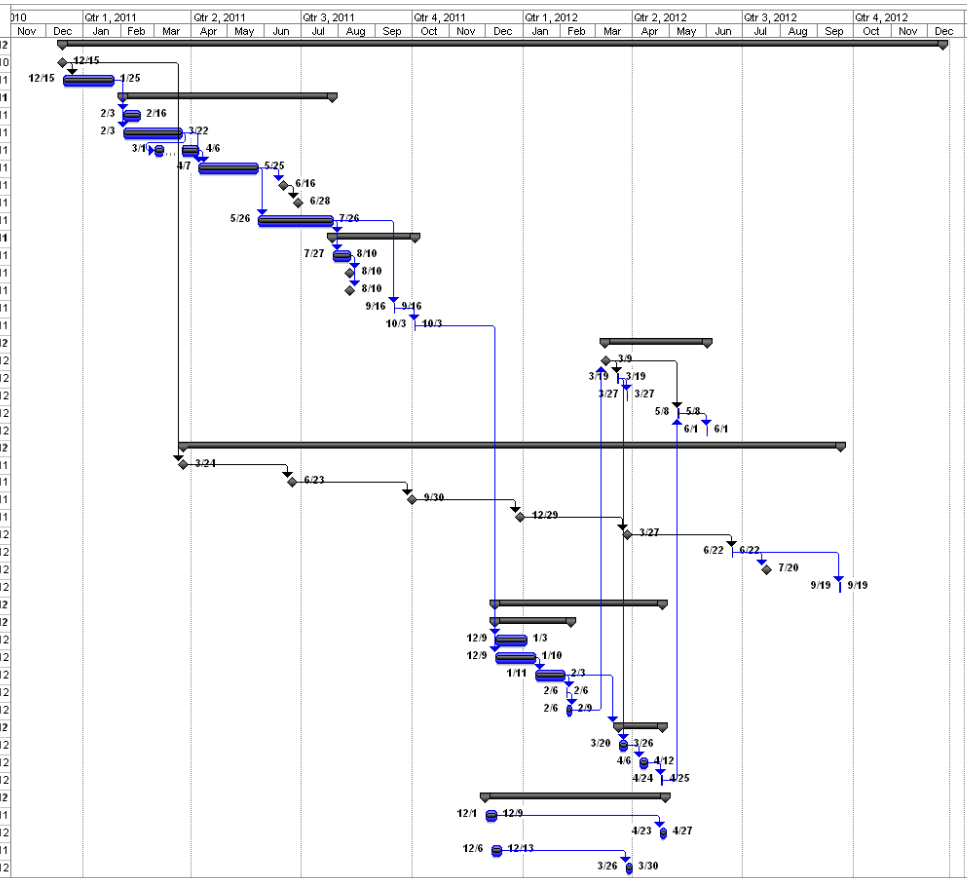
2.1 PROGRAM PLAN

Figure 2 shows the ITRB program plan truncated to WBS level 3. The plan is provided to provide the reviewer with a roadmap of the program tasks and their interrelationships and the various decision milestones throughout the program.

2.2 PROGRAM TEAM

Cobham formed a team and established contractual agreements with the teammates to execute the “Domestic Source for Improved Tail Rotor Blade Domestic Source ((ITRB-DS) Spar Program.” The key team members and responsibilities are summarized in **Table 1**.

ID	ℹ	Task Name	Start	Finish
1		**ITRB Development program**	**Wed 12/15/10**	**Thu 12/13/12**
2	✓	Contract Award Date	Wed 12/15/10	Wed 12/15/10
3	✓	Basis-Budget and Planning activity	Wed 12/15/10	Tue 1/25/11
4	✓	**Planning and Subcontract Phase**	**Thu 2/3/11**	**Tue 7/26/11**
5	✓	Layout Project Plan	Thu 2/3/11	Wed 2/16/11
6	✓	Prepare SOW and RFQ for Major Subcontractors	Thu 2/3/11	Tue 3/22/11
7	✓	Determine Sourcing of RTM injection system	Tue 3/1/11	Wed 4/6/11
8	✓	Place Major Subcontractors under contract	Thu 4/7/11	Wed 5/25/11
9	✓	Review of Design Concepts with Subcontractors	Thu 6/16/11	Thu 6/16/11
10	✓	ITRB Development program Kickoff MTG	Tue 6/28/11	Tue 6/28/11
11	✓	Initial Data Transfer from Boeing Mesa	Thu 5/26/11	Tue 7/26/11
12	✓	**Preliminary Engineering Tasks**	**Wed 7/27/11**	**Mon 10/3/11**
13	✓	Evaluate Data Package and distribute to subs	Wed 7/27/11	Wed 8/10/11
14	✓	PDR with FEA (Quartus)	Wed 8/10/11	Wed 8/10/11
15	✓	PDR with Braider - A&P	Wed 8/10/11	Wed 8/10/11
16	✓	Oringinal Data Transfer from Boeing	Fri 9/16/11	Fri 9/16/11
17	✓	Revised Data Transfer from Boeing	Mon 10/3/11	Mon 10/3/11
18	✓	**Final Data Transfer from Boeing (All file in Parasolid format)**	**Fri 3/9/12**	**Fri 6/1/12**
19	✓	Final OML CAD Data Transfer from Boeing (COBRP423000-101)	Fri 3/9/12	Fri 3/9/12
20	✓	Critical Component CAD and Drawing Data Transfer (COBRP423102, C	Mon 3/19/12	Mon 3/19/12
21	✓	Component CAD and Drawing data transfer (COBRP423101-001, COB	Tue 3/27/12	Tue 3/27/12
22	✓	Final Spar Assy Drawing Data Transfer (COBRP423000-101)	Tue 5/8/12	Tue 5/8/12
23	✓	Final Test Coupon Configuration Specification Transfer	Fri 6/1/12	Fri 6/1/12
24		**Interim Report Submittals**	**Thu 3/24/11**	**Wed 9/19/12**
25	✓	Interim Report #1 Submitted to ManTech	Thu 3/24/11	Thu 3/24/11
26	✓	Interim Report #2 Submitted to ManTech	Thu 6/23/11	Thu 6/23/11
27	✓	Interim Report #3 Submitted to ManTech	Fri 9/30/11	Fri 9/30/11
28	✓	Interim Report #4 Submitted to ManTech	Thu 12/29/11	Thu 12/29/11
29	✓	Interim Report #5 Submitted to ManTech	Tue 3/27/12	Tue 3/27/12
30	✓	Interim Report #6 Submitted to ManTech	Fri 6/22/12	Fri 6/22/12
31		Final Report Draft Submittal to ManTech	Fri 7/20/12	Fri 7/20/12
32		Interim Report #7 Submitted to ManTech	Wed 9/19/12	Wed 9/19/12
33	✓	**Braider Turned on to develop braid and fabricate necessary toolin**	**Fri 12/9/11**	**Wed 4/25/12**
34	✓	**Subscale Root End Braiding Development**	**Fri 12/9/11**	**Thu 2/9/12**
35	✓	Demo Options for lug region build up	Fri 12/9/11	Tue 1/3/12
36	✓	Boeing baseline braiding architecture development	Fri 12/9/11	Tue 1/10/12
37	✓	Ply dropoff termination development	Wed 1/11/12	Fri 2/3/12
38	✓	Pitch Cuff Section Vf% Verification	Mon 2/6/12	Mon 2/6/12
39	✓	A&P Demo	Mon 2/6/12	Thu 2/9/12
40	✓	**Subscale Tip End Braiding Development**	**Tue 3/20/12**	**Wed 4/25/12**
41	✓	SLS Model of Tip End From about STA42 to STA 66 (this will inclu	Tue 3/20/12	Mon 3/26/12
42	✓	A&P Practice Braiding and Build Up with Tow Wrap on SLS Model	Fri 4/6/12	Thu 4/12/12
43	✓	Demo at A&P	Tue 4/24/12	Wed 4/25/12
44	✓	**Cobham Design Support (Out of Scope Work)**	**Thu 12/1/11**	**Fri 4/27/12**
45	✓	Pitch horn attachment design with tooling concept to Boeing for reviev	Thu 12/1/11	Fri 12/9/11
46	✓	Design Update with Boeing Comments	Mon 4/23/12	Fri 4/27/12
47	✓	Tipend tooling redesign and submit to Boeing for review	Tue 12/6/11	Tue 12/13/11
48	✓	Design Update with Boeing Comments	Mon 3/26/12	Fri 3/30/12



ID	ℹ	Task Name	Start	Finish
49		**Tooling Fabrication**	**Mon 4/9/12**	**Mon 10/29/12**
50	✓	**RTM Tool**	**Tue 4/17/12**	**Thu 8/16/12**
51	✓	PDR with Tool Designer - G3	Tue 4/17/12	Tue 4/17/12
52	✓	Critical Design Review of Entire Fab Process	Wed 5/30/12	Thu 5/31/12
53	✓	Final RTM Tooling Design Review to Incorporate Changes from CD	Fri 6/8/12	Fri 6/8/12
54	✓	Tool Maker Turned on for Rough Machining	Fri 6/1/12	Thu 7/12/12
55	✓	Tool Maker Turned On for Final Machining	Fri 7/13/12	Thu 8/16/12
56	✓	**Mandrel Bonding Fixture**	**Fri 6/8/12**	**Fri 7/6/12**
57	✓	Design Fixture	Fri 6/8/12	Thu 6/14/12
58	✓	Fabricate Fixture	Fri 6/15/12	Fri 7/6/12
59	✓	**Machining Fixture**	**Mon 4/9/12**	**Thu 6/28/12**
60	✓	Design Fixture	Mon 4/9/12	Fri 4/20/12
61	✓	Fabricate Fixture	Fri 6/8/12	Thu 6/28/12
62		**Pitch Horn Assy Bonding Fixture**	**Wed 5/23/12**	**Mon 10/29/12**
63	✓	Design Fixture	Wed 5/23/12	Tue 6/5/12
64		Fabricate Fixture	Tue 10/16/12	Mon 10/29/12
65		**Raw Material Ordering**	**Thu 4/7/11**	**Tue 10/30/12**
66	✓	Rohacell	Tue 5/1/12	Mon 6/25/12
67	✓	Tip Fitting	Tue 5/1/12	Mon 7/2/12
68	✓	Lug fitting	Wed 5/9/12	Tue 7/3/12
69		Pitch Horn	Wed 5/2/12	Tue 10/30/12
70	✓	Inboard Pitch Bearing Retainer	Wed 5/2/12	Tue 6/26/12
71	✓	Round Trip to Boeing for Sol Gel Processing	Wed 6/27/12	Fri 6/29/12
72		Bushings	Wed 5/2/12	Thu 10/25/12
73	✓	Resin for Test Panels	Thu 4/7/11	Wed 5/4/11
74	✓	Resin For Spars	Thu 3/1/12	Wed 3/28/12
75	✓	Assemble Mandrels	Mon 7/9/12	Fri 7/13/12
76	✓	Braid 1st Preforms	Thu 7/19/12	Wed 8/29/12
77	✓	Braid 2nd and 3rd Preforms	Thu 10/4/12	Mon 10/15/12
78	✓	Braid Broadgood for Test Panel	Mon 6/4/12	Fri 6/22/12
79		**Material Coupon Testing**	**Mon 6/4/12**	**Fri 11/9/12**
80	✓	Wrap Up Test Panel Tool Design	Mon 6/4/12	Fri 6/8/12
81	✓	Fabricate Test Panel Tool	Mon 6/11/12	Fri 6/29/12
82	✓	Process Documentation	Mon 6/11/12	Fri 6/15/12
83	✓	Braider(A&P) Provide Material for Test Panel	Thu 8/30/12	Thu 9/6/12
84		Fabricate Material Test Panels with RTM Process	Mon 9/17/12	Wed 10/3/12
85		Panel testing	Wed 10/3/12	Wed 10/31/12
86		Test Results review by Boeing	Wed 10/31/12	Fri 11/9/12
87		**Fabrication of 2 Spars**	**Fri 7/20/12**	**Mon 12/10/12**
88	✓	Control Plan, WI, etc.	Fri 7/20/12	Thu 8/16/12
89	✓	Tool Proof RTM Tooling at Tool Maker Facility	Fri 8/17/12	Wed 8/22/12
90	✓	Setting Up RTM Tool at Cobham	Thu 8/30/12	Tue 9/18/12
91	✓	Trial Spar RTM Process Development & Fabrication -Iteration 1	Wed 9/19/12	Thu 9/20/12
92	✓	NDI Trial Spar Contour Inspection	Fri 9/21/12	Tue 9/25/12
93	✓	Machining Fixture Try Out	Wed 9/26/12	Tue 10/2/12
94	✓	Section and Polish Trial Part	Wed 10/3/12	Mon 10/8/12
95	✓	Process refinement (if necessary)	Tue 10/9/12	Mon 10/15/12
96	✓	RTM / Machine / Bond Pitch Horn on 2nd & 3rd iteration (Planned Delive	Tue 10/16/12	Thu 10/18/12
97		NDI Inspection	Fri 10/19/12	Fri 10/26/12
98		Contour Inspection	Mon 10/29/12	Tue 10/30/12
99		Spar Machining - Bore Lug Holes	Wed 10/31/12	Thu 11/1/12
100		Material Testing	Fri 11/2/12	Thu 11/22/12
101		Ship 3 spars to Boeing for bushing installation	Fri 11/2/12	Thu 11/8/12
102		Machine ID of Bushing to Specified Diameter	Fri 11/9/12	Thu 11/15/12
103		Pitch Horn Bonding	Fri 11/16/12	Wed 11/21/12
104		A-Scan of Bondline	Thu 11/22/12	Wed 11/28/12
105		Machine fastener holes and install fasteners for pitch horn and press	Thu 11/29/12	Fri 11/30/12
106		Press fit pitch bearings	Mon 12/3/12	Mon 12/3/12
107		Deliver 2 spars	Mon 12/3/12	Mon 12/3/12
108		Dimensional and Material Documentation	Fri 11/23/12	Mon 12/10/12
109		Draft Final Report Preparation	Fri 10/19/12	Thu 11/1/12
110		Due day for any feedback from ManTech	Fri 11/30/12	Fri 11/30/12
111		Final Report preparation Incorporating Feedback from draft report	Mon 12/3/12	Thu 12/13/12
112		Final report submittal	Thu 12/13/12	Thu 12/13/12

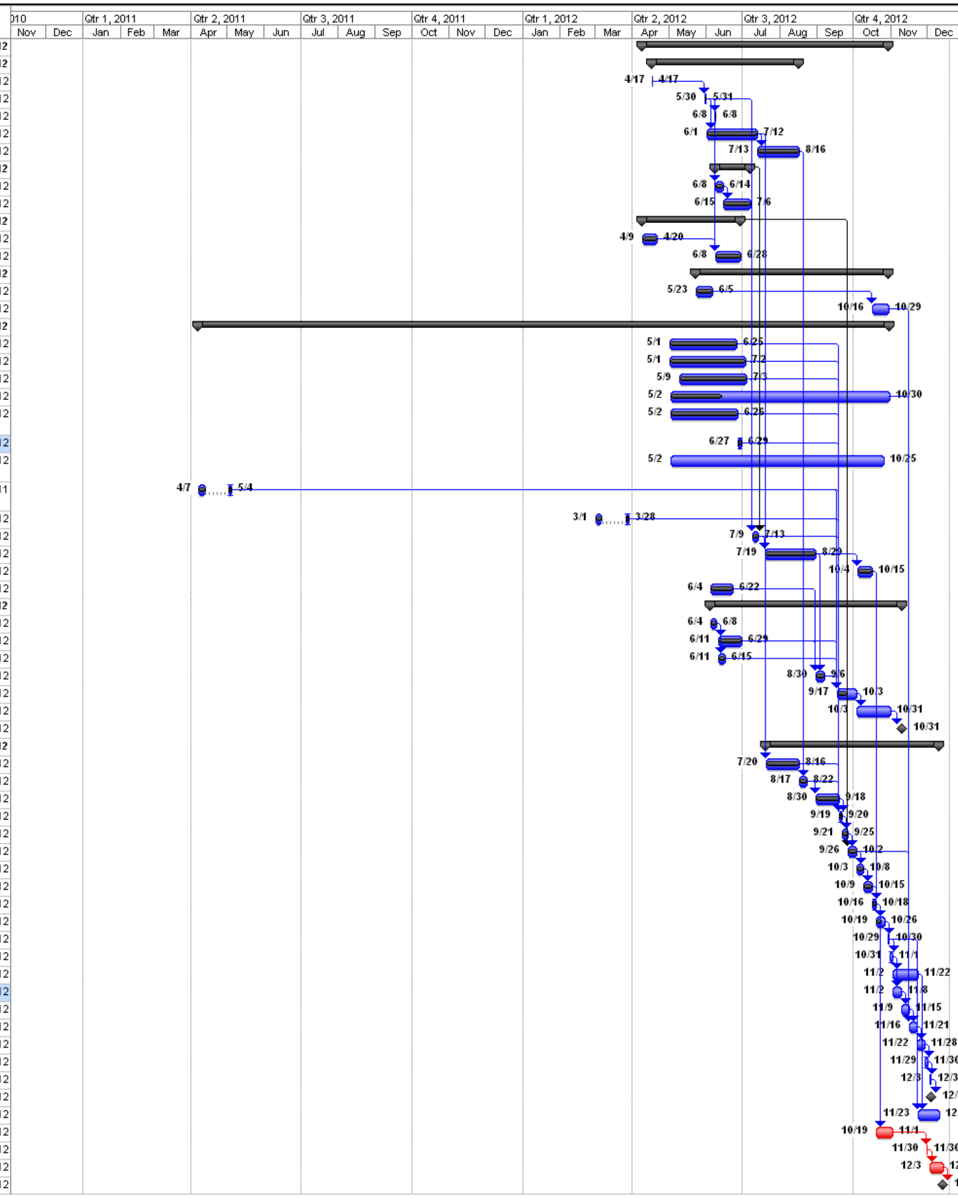


Figure 2 ITRB program plan

Table 1 Major Teammates for ITRB-DS

Company	Location	Contact(s) / Roles	Major Activities
Boeing Aerospace	Mesa, Arizona	Joe Buffington (Apache Modernization Program) Dennis Kennedy	Provide spar requirements package; spar OML solid model; install metallic lug bushings; provide un-sized pitch bearings
A & P Technology	Cincinnati, Ohio	Phil Lariviere Jessica Morris	3-D braiding of materials for test panels, developmental sub-scale coupons and full-scale developmental braids per Cobham requirements for inclusion into Cobham developmental spars
G3 Engineering, LLC	Murray, Utah	Richard J. Gardiner Randon Gardiner	Support test panel design and full-scale spar RTM tooling design, tooling fabrication and provide additional RTM technical support to Cobham as required.
Quartus Engineering Inc.	San Diego, California	Jeremy Gustin Chris Flanigan	Provide structural analysis of spar for ITRB to assure that design will meet requirements.

At the onset of this program, an overall design and fabrication process flow chart was generated to clearly define all IPT interactions and roles in the program, **Figure 3**.

3. PRODUCT DESCRIPTION

The composite spar is an integral structural member for the new composite tail rotor blades. Since they are designed to replace the current metallic tail rotor blades, the design goal is for them to have similar sectional moduli, mass distributions, modal frequencies, and shape as the metallic blades. The initial program design process scope included design parameter definition, material selection, FEA analysis, spar architecture design, test panel fabrication to verify material properties, and design iterations. This work was guided by general spar requirements provided by Boeing. However, mid-way through Cobham's completion of FEA analysis Boeing was able to provide their ITRB spar design, rendering additional Cobham spar design work as unnecessary. Cobham then focused on the Boeing design and started the fabrication phase with Boeing drawings. The fabrication phase consisted of tooling design and fabrication, braiding development, material procurement, and spar fabrication. The introduction of the specific spar design data by Boeing to align with the Army ITRB program was an important step in being apply the ManTech program results to the Army program.

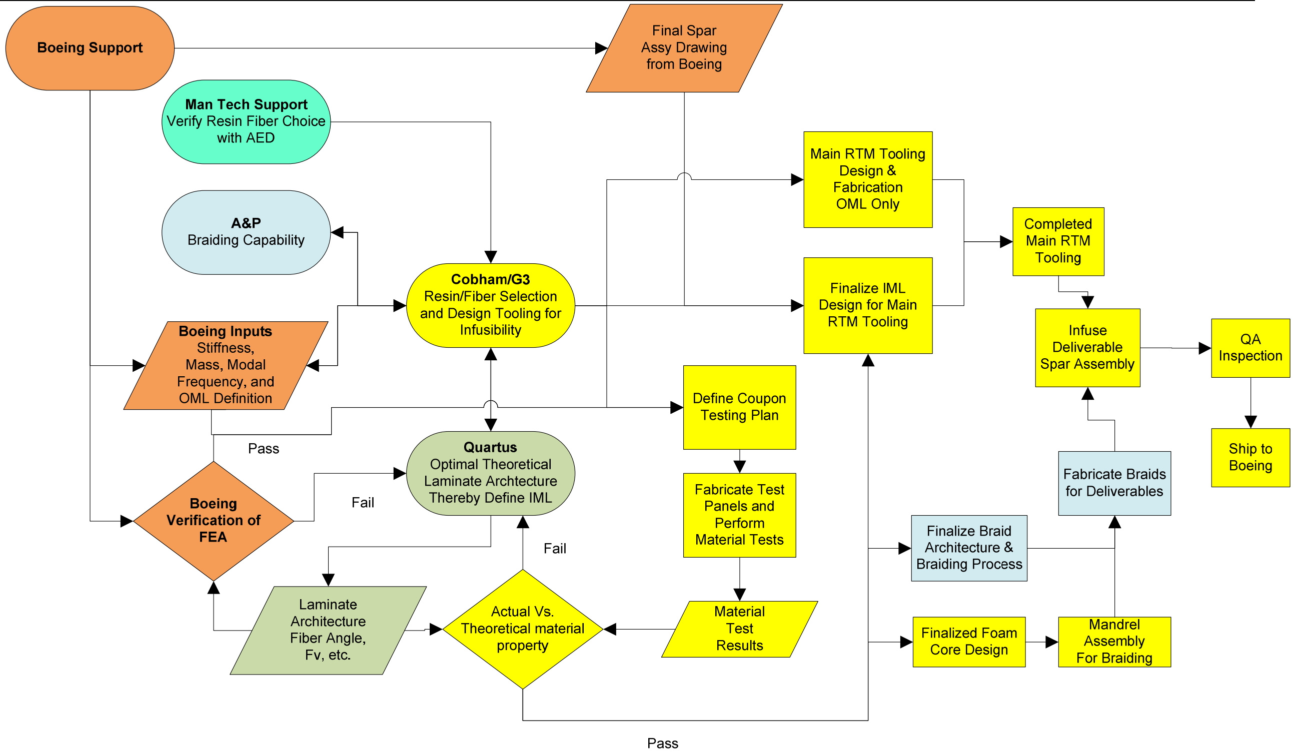


Figure 3 Original Overall Design and Fabrication Process Flow

The final deliverable spars were long tubular shaped structures with geometrical features along their length. They had varying cross sections spanwise from root end to tip end. At the core of these spars is a preform mandrel assembly that consists of foam and metallic components. Then a triaxial preform consisted of layers dry carbon fiber was braided around the preform mandrel assembly in an overbraiding machine that resulted in final preform assembly. The molding process included inserting the preform into a coffin style RTM mold and injecting the selected resin system into the mold cavity under pressure to infuse the preform assembly. Once the cavity was full of resin and preform, the entire mold was heated to a prescribed cure cycle. After which, as-cured spars were deflashed, trimmed, and machined to final configuration. Finally, a pitch horn was bonded to the root end of the spar and pitch bearings were installed.

4. MATERIAL SELECTION

When Cobham started the program, Boeing had provided sectional moduli, mass distribution, and modal frequencies requirements. Based on these requirements, Cobham established a list of possible resin and fiber candidates; see **Table 2** and **Table 3**. Then, Cobham generated a weighted selection matrix that rated each material candidate. For fiber, the selection criteria were ~35 MSI for tensile modulus, 550 KSI minimum tensile strength, and low fuzz during braiding. Main parameters considered for resin selection were high toughness as measured by “Fracture Toughness” and “Strain Energy Release,” relatively short cure cycle, long pot life, low injection temperature, continuous service temperature above 165˚F (74˚C), availability, and cost.

Based on the outcome of these trades one fiber/resin combination was selected for final laminate design and FEA analysis.

Table 2 Fiber Candidate Matrix

Type	E (mpsi)	UTS (kpsi)	Source
HTA40*	34.5	573	Toho
T700G*	34.8	711	Toray
AS4D	35	610	Hexcel
AS7*	35	700	Hexcel
G30-700	35	700	Hexcel
T400H	36.3	640	Toray
T650-35*	37	620	Amoco
TRH50	37	700	Grafil
G50-300	40	760	Hexcel
M40J	40	600	Hexcel
IM2A	40	700	Hexcel
IM7*	40	780	Hexcel
42-650/MR40	42	640	Mit./Grafil
T650-42	42	700	Amoco
T40	42	820	Amoco
G40-800	42	850	Toho
IM9	42	920	Hexcel
M30	42.7	569	Toray
M30G	42.7	739	Toray
M30S	42.7	796	Toray
T800H	42.7	796	Toray
T1000G	42.7	924	Toray

* Fibers that are braiding friendly (based on experience at A&P technology)

Table 3 Resin Candidate Matrix

Resin Name	Neat Resin Properties																						
	One Part or Two Part	Type	Shelf Life (Months)	Storage Temp (˚F)	Pot Life @ RT (Days)	Injection Window (minutes)	Cured Density (g/cc)	Injection Temp (˚F)	Viscosity @ Injection (cp)	Cure Temp (˚F)	Cure Time (hrs)	Glass Transition Temp Dry (˚F)	Glass Transition Temp Wet (˚F)	Moisture Uptake (%)	Flexural Strength (ksi)	Flexural Modulus (ksi)	Flexural Elongation (%)	Compressive Strength (Dry) (ksi)	Tensile Strength (ksi)	Tensile Modulus (ksi)	Tensile Strain (%)	Strain Energy Release (Dry) (in-lb/in^2)	Fracture Toughness (psi(in).5)
HexFlow VRM 37	Two	Epoxy	NA	NA	NA	120	1.15	130	~400	212	6.5	363	307	0.8	21	512	NA	NA	NA	NA	NA	2.3	712
HexFlow RTM 6	One	Epoxy	9	0	15	150	1.14	176	~200	320	~4.5	~370	338	2.5	19.14	478.6	NA	NA	10.9	419.2	3.4	1.0	NA
Cycom 823 RTM	Either	Epoxy	6	0	4	1440	1.23	75	250	255	~2	275	250	1.2	20.5	480	7.6	NA	11.3	410	8.8	5.1	1400
Cycom 875 RTM	One	Epoxy	12	0	30	1440	1.24	140	200	255	~3	345	379	1.2	14.2	525	3.6	NA	6.8	450	1.7	0.6	450
Cycom 890 RTM	One	Epoxy	12	0	30	1440	1.22	175	250	355	~3.5	408	408	1.2	19.7	454	3.3	NA	10	440	6.3	1.2	800
Cycom 977-20 w/ Priform	One	Epoxy	12	0	30	1440	NA	140	200	350	~8	424	349	1.1	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cycom 5250-4 RTM	One	BMI	6	0	30	1440	1.25	200	500	400	~2.5	490	390	4	23.5	NA	4.5	NA	15	0.67	4.9	0.8	NA
Cycom 5555	One	Epoxy	6	0	14	240	1.14	205	240	320	~5	358	345	1.16	16.2	440	NA	22.9	NA	NA	NA	1.1	700
Cycom 5575-1 RTM	One	Cyanate Ester	6	0	14	150	1.21	205	250	350	~4.5	448	439	1.16	16	610	NA	33.8	8.3	540	NA	NA	NA
Prism EP2400	One	Epoxy	12	0	28	600	1.24	212	300	356	~3	354	325	NA	NA	NA	NA	NA	0.49	13800	7.2	1.6	22.2
Hysol EA 9150	Two	Epoxy	12	RT	480	480	1.18	130	250	250	~2	270	NA	0.03	NA	NA	NA	14.5	11.46	414	5	NA	NA
PR520	One	Epoxy	6	0	NA	NA	1.25	200	NA	370	~2.5	304	282	NA	22.2	500	NA	18.5	11.9	580	NA	8.05	2000

Resin Name	Laminate Properties																		
	Fiber Volume (%)	Tensile Strength (Dry) (ksi)	Tensile Strength (HW) (ksi)	Compression Strength (Dry) (ksi)	Compression Strength (HW) (ksi)	Compression Modulus (Dry) (msi)	Compression Modulus (HW) (msi)	Open Hole Tensile Strength (ksi)	Open Hole Compression Strength (Dry) (ksi)	Open Hole Compression Strength (HW) (ksi)	Inter Laminar Shear (Dry) (ksi)	Inter Laminar Shear (HW) (ksi)	In Plane Shear (Dry) (ksi)	In Plane Shear (HW) (ksi)	Flexural Strength (Dry 3-point) (ksi)	Flexural Strength (HW3-point) (ksi)	Flexural Modulus (Dry 3-point) (msi)	Flexural Modulus (HW 3-point) (msi)	Comments
HexFlow VRM 37	NA	NA	NA	119.1	88.3	NA	NA	NA	38	32.8	10.8	NA	NA	NA	119.8	NA	7.54	NA	SM Carbon 3K 195GSM PW
HexFlow RTM 6	57	124.7	120.4	101.5	77.7	NA	NA	NA	NA	NA	9.72	NA	14.5	11.3	NA	NA	NA	NA	HR 6K 5HS 370GSM
Cycom 823 RTM	52	NA	NA	114	81.2	8.58	8.7	NA	NA	NA	10.5	6.64	NA	NA	160	130	10.4	69.7	6K-HS-HTA-370
Cycom 875 RTM	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cycom 890 RTM	55	128	122	103	85	8.8	8.9	NA	NA	NA	11	6.5	14.1	9.8	151	104	8.9	8.8	AS4-GP 6K-5HS
Cycom 977-20 w/ Priform	NA	111	128	87	70	9	9	44	40	37	11	8	15	13	NA	NA	NA	NA	6K-HS-HTA-370
Cycom 5250-4 RTM	58	105^	82^	86^	36^	NA	NA	NA	77	70	12	6.1	NA	NA	160	91	10.5	10.5	IM7-6K-4HS ^AS4-3K-70PW
Cycom 5555	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cycom 5575-1 RTM	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Prism EP2400	60	98.9	NA	83.2	76.6	9	8.8	NA	NA	NA	11.5	NA	17.1	NA	NA	NA	NA	NA	Bi-Axial NCF 12K HTS40
Hysol EA 9150	NA	NA	NA	27.8*	NA	NA	NA	NA	NA	NA	7.2*	NA	NA	NA	86*	NA	NA	NA	Laminate made with 7781 glass
PR520	NA	181	NA	92.9	NA	8.1	NA	42.1	35.4	NA	11	NA	17.6	14.5	NA	NA	NA	NA	Woven IM7GP 6K-4HS

N.A. – Not Available

Fiber candidates were down selected to T700G and IM7. T700G fiber was the primary selection due to its acceptable mechanical properties and flat tow profile, which makes it ideal for the braiding process. Additionally, it's about 50% less costly than higher modulus fibers. In case a higher modulus fiber is necessary, IM7 was the backup selection.

Resin candidates were down selected to Cycom 823 RTM and PR520. Two main differences between these resins are the higher wet Tg of the PR520 resin (282 vs. 250ºF) and the roughly three times higher cost for the PR520. Cycom 823 was selected as the primary choice with PR520 as backup. Approx. 20lbs of Cycom 823 was procured to mitigate risk of long lead time, 12-14 weeks.

5. FEA ANALYSIS

Once T700G/Cycom 823 fiber resin system were selected, Cobham started FEA analysis. First laminate properties were calculated using Classical Lamination Theory based on published material data for constituent fiber and resin. Then laminate was designed using calculated laminate properties to requirements in axial stiffness, bending stiffness 1, bending stiffness 2, torsional stiffness, and mass distribution. See **Figures 4** to **9.**

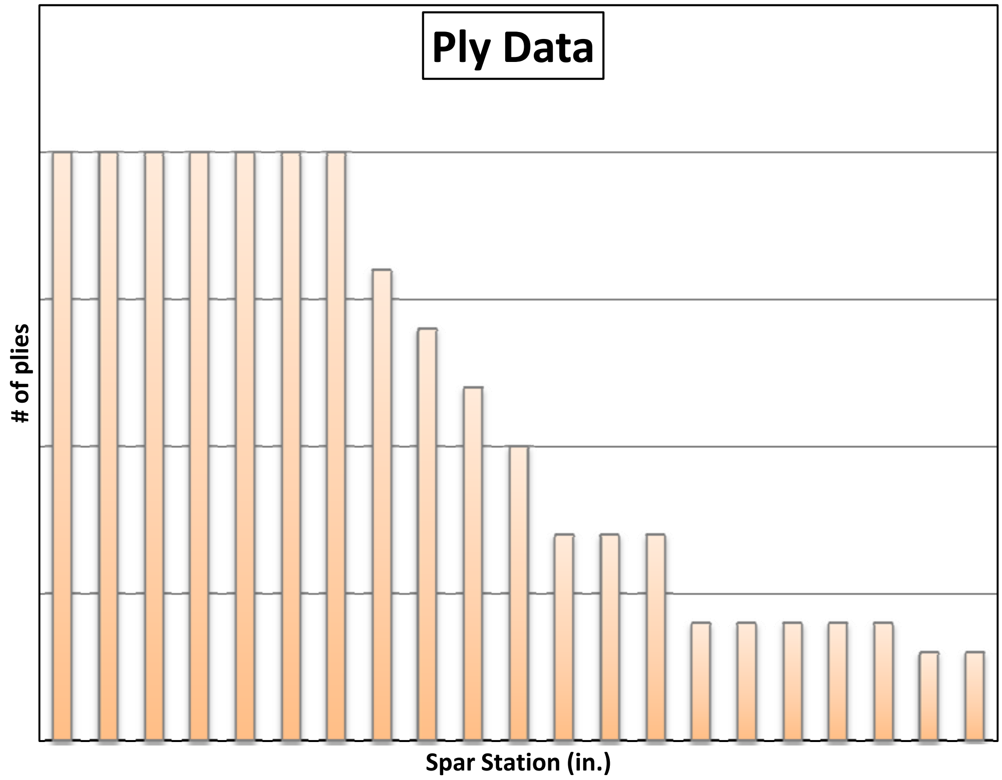


Figure 4 Cobham Laminate Design

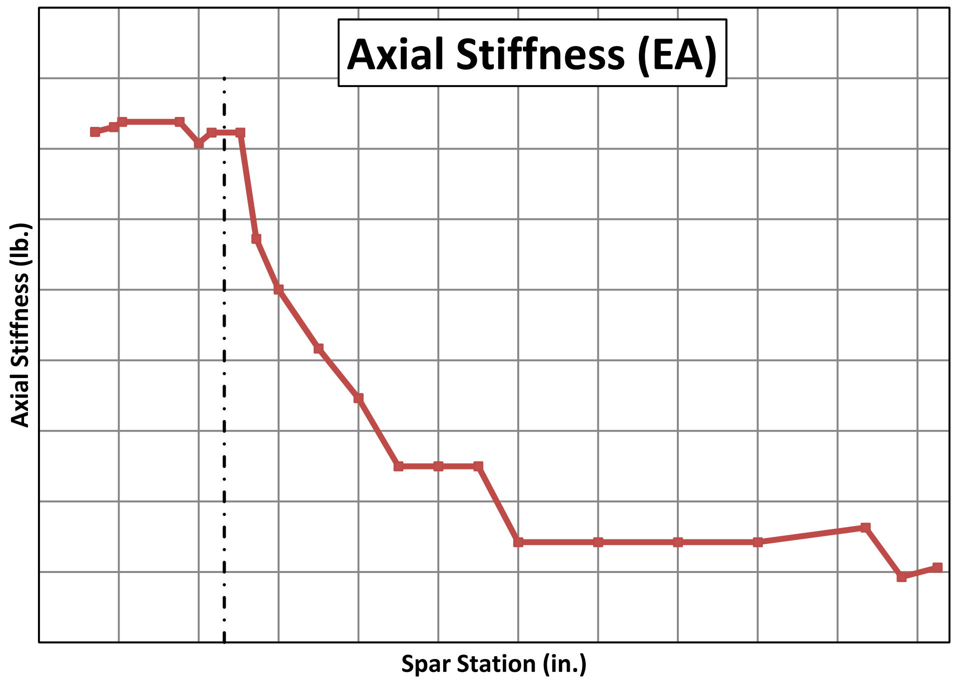


Figure 5 Axial Stiffness for Cobham Design

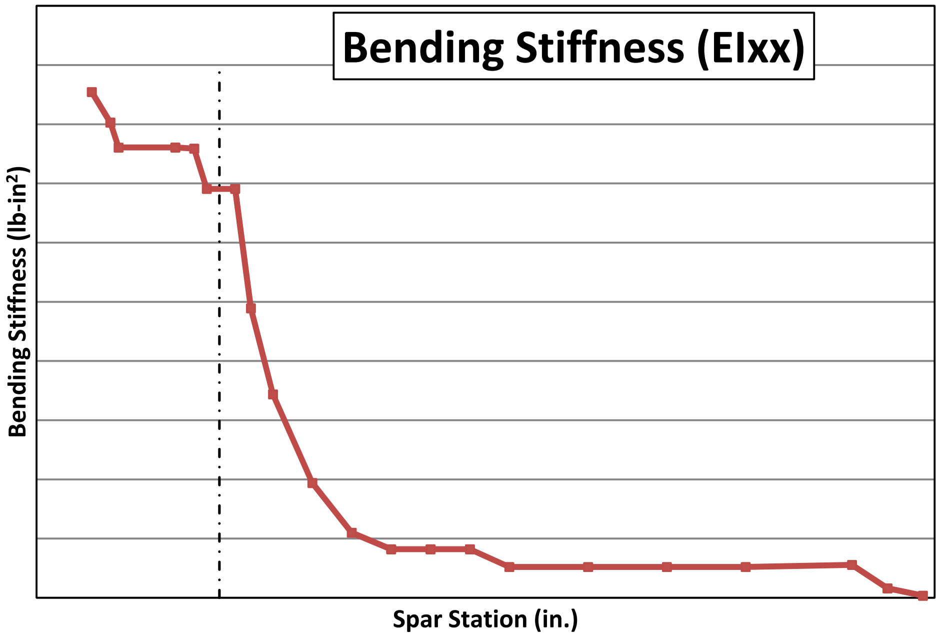


Figure 6 Bending Stiffness EIxx for Cobham Design

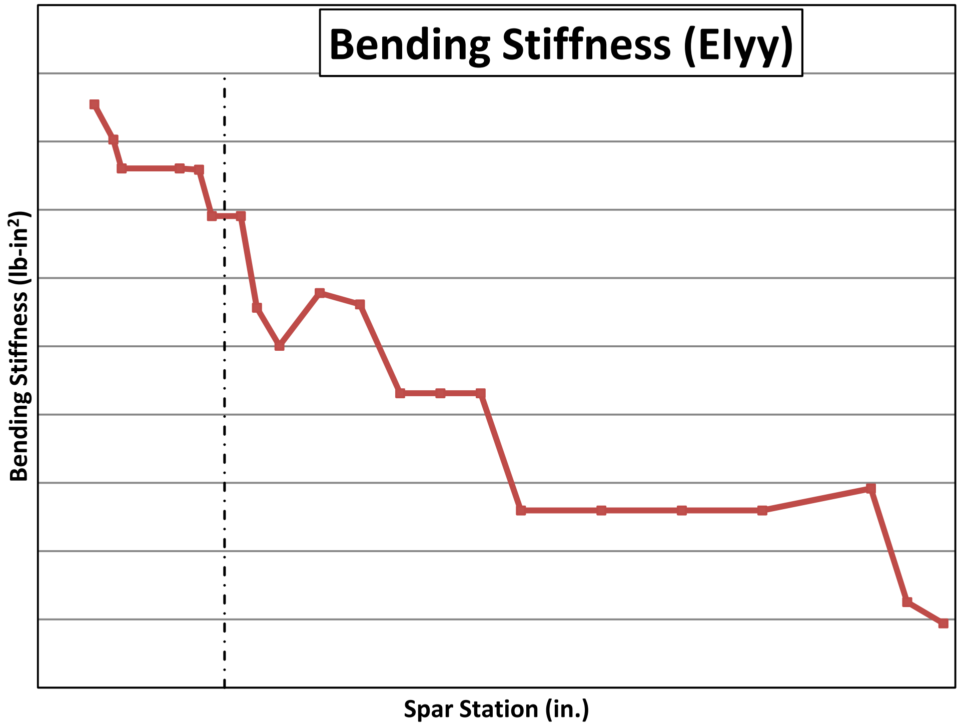


Figure 7 Bending Stiffness EIyy for Cobham Design

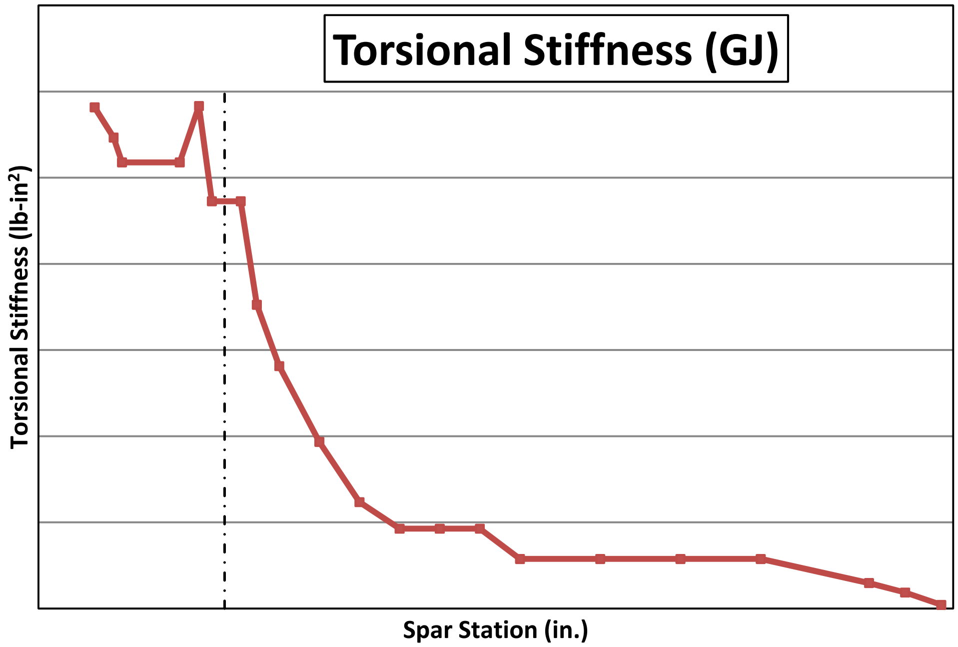


Figure 8 Torsional Stiffness for Cobham Design

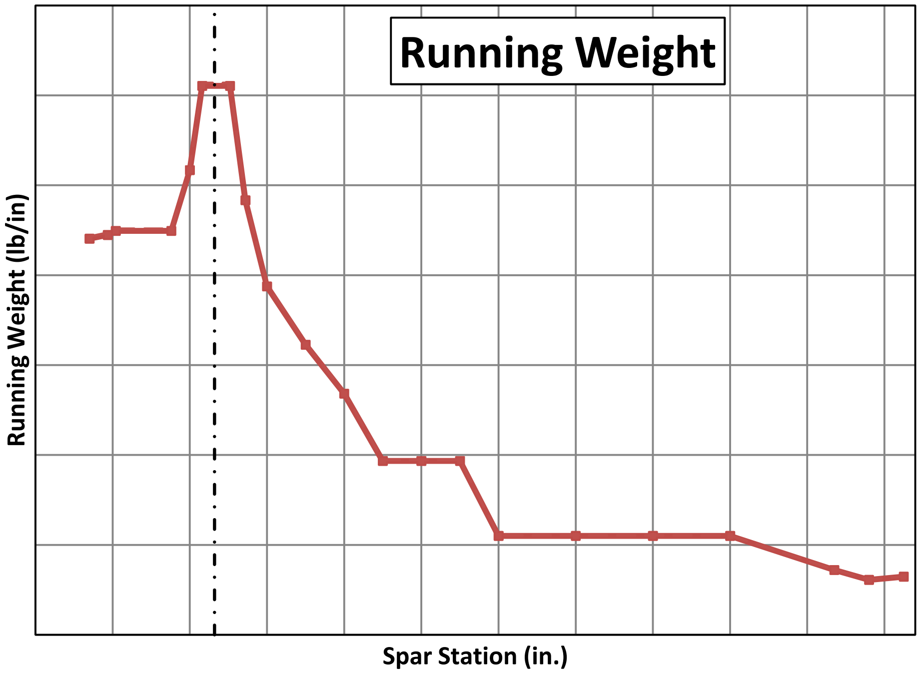


Figure 9 Mass Distribution

As a result of the realignment of the program to the specific Boeing ITRB drawings and requirements, the designs, based on the results shown above were not used for tooling and part fabrication.

6. PROGRAM ALIGNMENT TO ARMY ITRB DESIGNS

The Cobham design results were reviewed by ManTech and Boeing Mesa before proceeding any further. Boeing Mesa determined that they could provide Cobham with details of their current ITRB Spar design. Prior to this, Boeing had mainly commented on Cobham's design (and choice of materials) and provided goals for mechanical and physical properties (strength, stiffness, modal values and running weight). Boeing accelerated the development of the program and the utility of the program products by providing their braiding architecture design as it aligned the program to Army ITRB requirements and enabled Cobham to produce spars for delivery to Boeing that would match or potentially and hopefully exceed the performance of non-US sourced spars currently being developed. Boeing indicated that the materials (fiber and resin) utilized in their design were different from the fiber and resin selected by Cobham (T700G fiber and Cycom 823 RTM resin) and that they desired to increase fiber volume to yield improved mechanical performance. Boeing agreed that if the 823 resin had the potential to produce an improved toughness spar, and if Cobham could demonstrate equivalency or improvement in laminate properties of the T700G-Cycom 823 RTM system over that of the Boeing system, they would encourage us to make the demonstration spars from our selected fiber/resin system.

Boeing provided Cobham with a modified spar drawing giving the details of their current braid/fiber architecture. The drawing also included the Boeing choice of fiber and resin.

In addition, at the same time as providing us with the revised spar drawing Boeing provided Cobham with an updated Outer Mold Line (OML) drawing that enabled Cobham to complete the design of the spar RTM tool. This updated OML incorporated the latest ITRB design changes. The original “Overall Design and Fabrication Process Flow” in **Figure 1** was updated to reflect new program structure as shown in **Figure 10.**

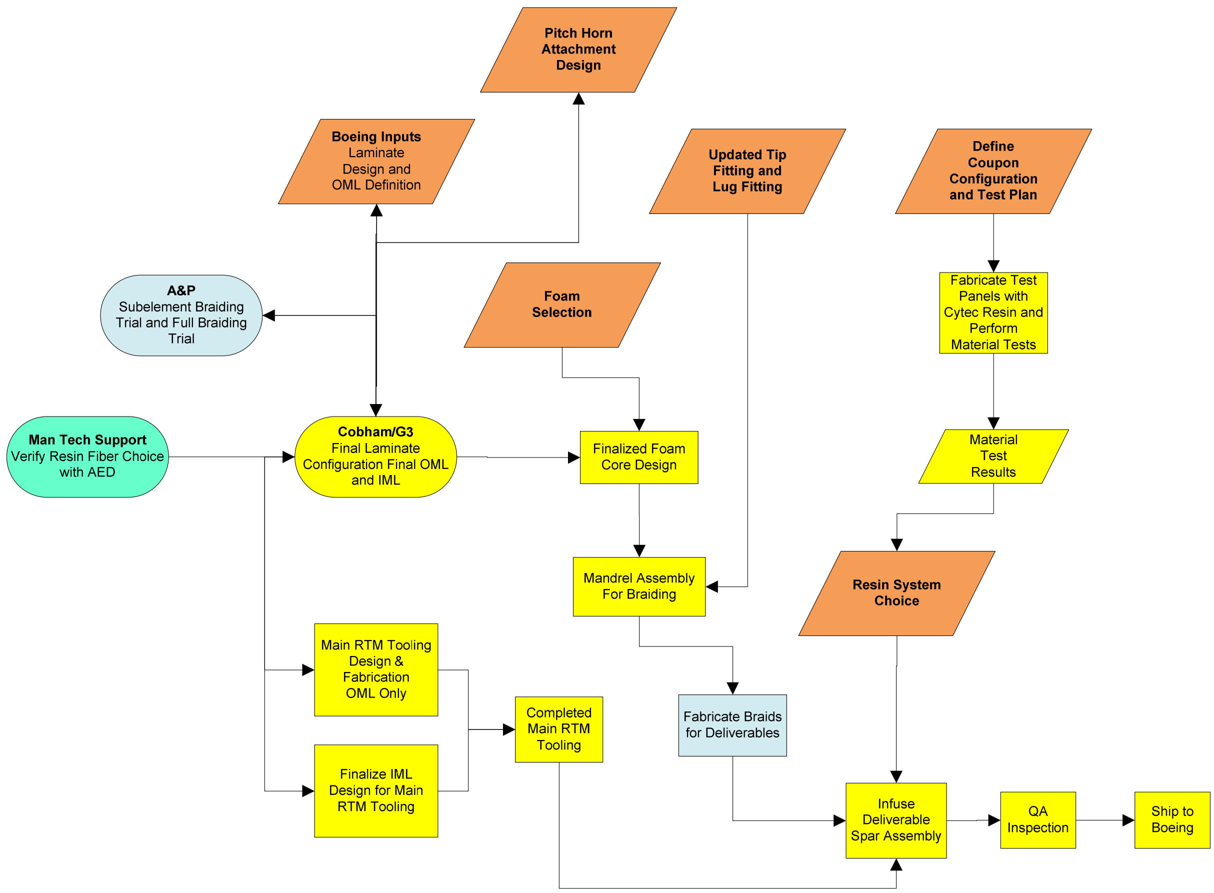


Figure 10 Updated Overall Design and Fabrication Process Flow

This opportunity was a win-win situation for the Government, Cobham and Boeing. Because of a reduction in design iterations, it resulted in a wash in overall schedule despite the delay in completing the Spar RTM tool design. It also had the potential to hold costs despite the need to redo some analysis and potentially not use the 20 pounds of Cycom 823 RTM resin we ordered for inventory. In order to make the transition to the new architecture, Cobham needed to:

- Review the revised Boeing Design for producibility and potential production cost issues
- Suspend all laminate design activities
- Discuss the modified braid architecture with the braiding partner, A&P Technology to make sure they are capable of producing the required architecture

7. TOOLING DESIGN AND FABRICATION

For this program numerous tooling and fixtures are required. This section will highlight just the spar RTM mold.

a. Preform Mandrel Bonding Fixture

b. Spar RTM Mold

c. Machining/Trim Fixture

d. Pitch Horn bonding fixture

e. Lid Roll Over Tool

f. Mold Cart

g. Rotary Pitch Horn Fastener Machining Fixture

h. Flat Panel RTM Mold

i. Bulk Factor Trial Tool

For the most critical piece of tooling, the Spar RTM mold, a conceptual tooling design was presented at the program kick-off meeting and finalized based on the updated Technical Data Package from Boeing in March 2012. Cobham actively fine tuned the tooling approach with inputs from G3 and A&P. In order to have a successful RTM part, tooling design is predicated on a laminate structure, which is predicated on braider capability. However, laminate structure must be designed with infusibility in mind. So all parties worked closely together from the conceptual stage. The final tool design consisted of over 20 tooling pieces arranged in a coffin style mold. All pieces are indexed to ensure proper position of OML and IML tooling pieces. Integrated resin channels ensured proper transfer of resin throughout cavity.

The RTM mold was machined from Aluminum billets. Cobham accepted the tooling on site at Dramco Tool and Die. The key tooling characteristics inspected were part contour, parting line match up between tooling pieces that defines part geometry, and gap check between the lid and the rest of mold. All key characteristics above were accepted. The only request prior to delivery was additional polish of tooling surface at a couple small areas to prevent leak during resin injection operation.

Once the RTM mold was accepted, it was hard anodized and then shipped to Cobham.

8. COBHAM EQUIPMENT SET UP

In order to support spar fabrication, Cobham modified existing presses, fabricated carts, tool lid holding fixtures, established a safe and efficient work cell that can become production worthy with just few minor upgrades, and completed a thermal survey of the RTM mold.

8.1 PRESS MODIFICATION

Modification to existing Cobham RTM presses was completed to accept the ITRB-DS spar RTM mold as shown in **Figure 11**. V-groove guide rails were installed to assist with transporting the mold in and out of the presses. The press opening had to be adjusted to accommodate mold thickness. To ensure even temperature on the mold, platens were relocated from the middle of individual press to be in the middle of a 2-press combination. Hydraulically, a stand alone hydraulic pump system was used to provide up to 3,000 psi hydraulic pressure to the presses. This pressure is needed to ensure that the mold stays closed when the mold cavity is under injection and hold pressure prior to gelation.

Figure 11 View of Press, Electrical Cabinet, and Hydraulic Pump

8.2 TOOLING CART

To assist with handling the ~900lb RTM mold, a special cart was fabricated as shown in **Figure 12**. Precision v-rails were mounted to custom machined brackets which are then mounted to a height adjustable, high load capacity cart. The mold bottom is then lowered onto the cart supported by a total of 8 v-groove wheels that match up to the rails on the cart. For safety, stopper plates were installed to both ends of the cart to prevent the mold from sliding off accidentally. Finally, rails on the cart line up with rails in the press.

Figure 12 Tooling Cart

8.3 TOOLING LID ROTATING FIXTURE

While the mold bottom resides on the cart, the mold lid is mounted securely to a tool lid rotating fixture. This fixture has a pair of high load capacity metal rollers mounted to both ends of a piece of structural steel. Each pair of rollers is designed to capture the shafts mounted to both ends of the tool lid. Additionally, a safety pin can be put in place to prevent unwanted lid rotation. This way, the heavy mold lid can be rotated easily into position for the operator to perform necessary tool maintenance on the part surface and then rotated back to be ready for final tool assembly.

8.4 RTM MOLD THERMAL SURVEY

With presses modified and the RTM mold ready, Cobham performed a thermal survey with the mold empty to configure the cure profile. To monitor the thermal survey, there are three thermocouples (TC) on the mold lid and three TCs on the mold bottom. TCs are located down the centerline of the mold to align with the tip end, midspan, and root end of the part. Tips of these TCs are just .25” away from mold surface to ensure accurate temperature measurements. **Figure 13** shows the result of the thermal survey. The maximum range between all six TCs is 10˚F which was within tolerance.

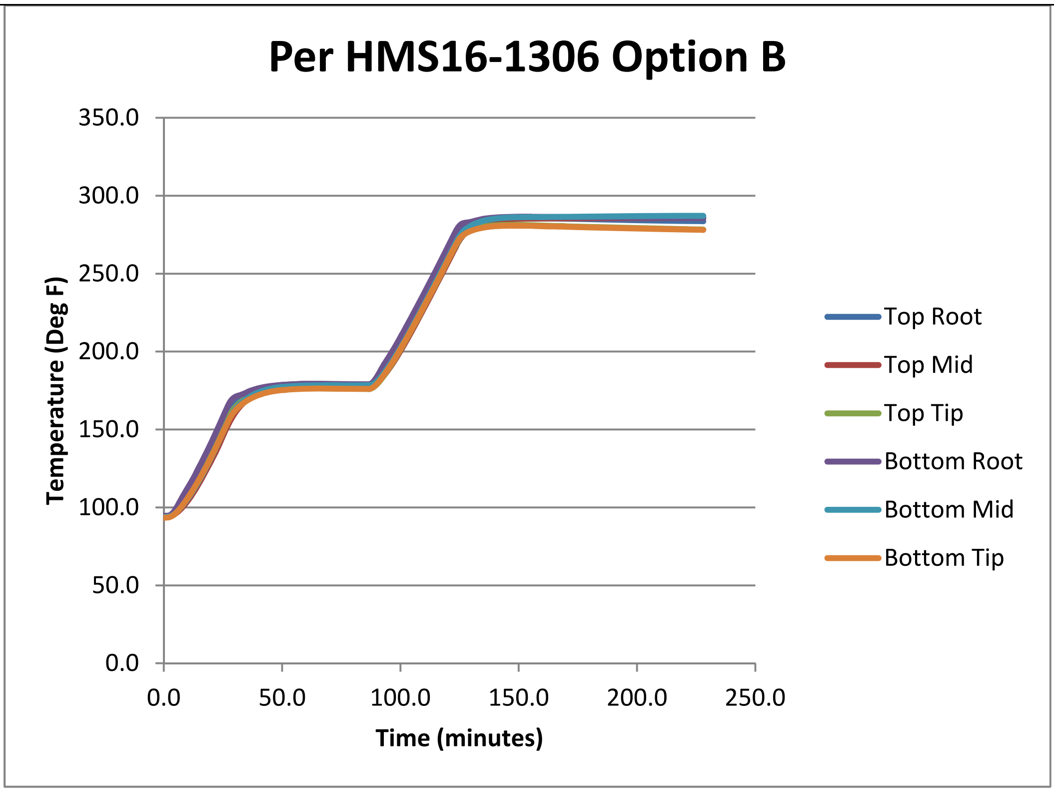


Figure 13 Thermo Data from Thermo Survey of Empty Mold

9. BRAIDING

Braiding the triaxial braid to Boeing's specification required significant development by A&P. Cobham fabricated several spar mandrels out of SLA material and provided them to A&P to support the braiding process development and subsequent trials. The SLA pieces represented the root section, tip section, and the entire spar. The objective of these trials is to investigate braiding techniques required for producing full preform.

Through these braiding trials, A&P had developed techniques that produced a repeatable, precise, and low bulk factor preform. Bulk factor is critical during insertion of the preform assembly into the tool cavity.

9.1 SUBSCALE BRAIDING DEMO (ROOT SECTION)

The subscale braiding demo took place at A&P from 2/7/12 to 2/10/12. It was attended by representatives from Boeing Mesa, Mantech, Apache PMO, G3, and Cobham. This demo focused on the root section of the spar, which included the critical lug region. Cobham supplied a SLA model of the mandrel for A&P to support the braid. The braiding development trials were completed successfully.

At the end of subscale braiding trial, ITRB-DS team had demonstrated the following:

- Capability to recreate current baseline Boeing Mesa braid architecture

- Higher fiber volume (%Vf) than current baseline Boeing Mesa ITRB spar can be achieved with a tighter braided preform. This was accomplished with a demonstration tool designed by G3/Cobham and fabricated by as shown in **Figure 14**
- Multiple options for lug region build ups
- Multiple tackifying options
- Alternative ply drop off method to achieve the desired thickness profile

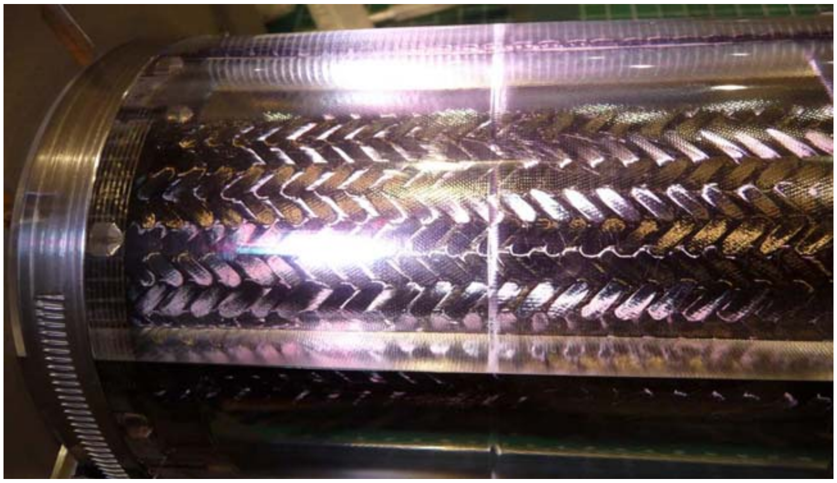


Figure 14 Higher Fiber Volume Demonstration Tool

9.2 SUBSCALE BRAIDING DEMO (TIP SECTION)

The second subscale braiding demo took place at A&P April 2012. It was attended by representatives from Boeing Mesa, Mantech, Apache PMO, and Cobham. This demo focused on the tip section of the spar, which included the critical lug region. Cobham supplied a SLA model of mandrel for A&P to braid onto. During this demo, every planned trial was completed successfully.

9.3 FULL SCALE BRAIDING

Next Cobham provided A&P with a full scale SLA model of the mandrel. A&P used it to prepare for the full scale mandrel braiding. The mandrel was bonded and assembled at Cobham in San Diego. When the mandrel was fully assembled, it was packaged in a moisture proof bag and shipped to braider A&P in a custom crate to prevent damage during transit. This same shipping setup has been used successfully for each of the four mandrels shipped from Cobham.

During full scale braiding, A&P had set up multiple in-process inspection points to ensure braiding proceeded according to plan and to capture processing data to be fed back to the Boeing Mesa design team.

10. SPAR FABRICATION

Cobham successfully injected the first spar for ITRB-DS program on September 19, 2012. Representatives from Mantech, Boeing, A&P, G3 and Dramco Tooling were on site to witness the first part out of the mold. The entire process proceeded according to plan.

10.1 SPAR ASSEMBLY INJECTION

Injection of the first spar assembly followed these steps: RTM mold prep, preform insertion into RTM mold, RTM mold closure, RTM mold insertion into press, evacuate RTM mold of air, resin injection, cure cycle, and final demold.

10.1.1 Mold Preparation

RTM mold preparation consisted of clean, seal, and release. This is a common composite manufacturing practice. First, all tooling pieces that will come into contact with resin are solvent cleaned. Then, all tooling surfaces are sealed with RS415 Mold Sealer™ from Marbocote. Finally, several layers of Marbocote 75ECO mold release is applied to ensure part / tool separation during demold.

10.2 PREFORM INSERTION INTO RTM MOLD

After mold prep was completed, the mold was transported into a climate controlled room. Here the preform was taken out of the crate and removed from moisture proof bagging. First a weight measurement was taken. Then it is laid into the mold bottom with all the mold cavity tooling pieces assembled.

10.2.1 Mold Closure and Insertion into Press

Once the preform was installed into the mold, the lid was lowered to complete mold assembly. This was a critical step in the RTM process. The Mold would not close if there was any miscalculation for tooling and any extra bulk in the preform. The loaded tool, prior to insertion into the press, is shown in **Figure 15.** The rails used to align the mold during insertion into the press are also shown in the figure.

The braiding trials and tooling calculations paid off and the tool closed as designed once it was in the press under hydraulic pressure as shown in **Figure 16**.

Figure 15 Mold Closure Process

Figure 16 Mold Insertion into Press

Once the hydraulic pressure was applied, the mold closed completely as verified by inspection with feeler gages. The closed mold is shown in **Figure 17**.

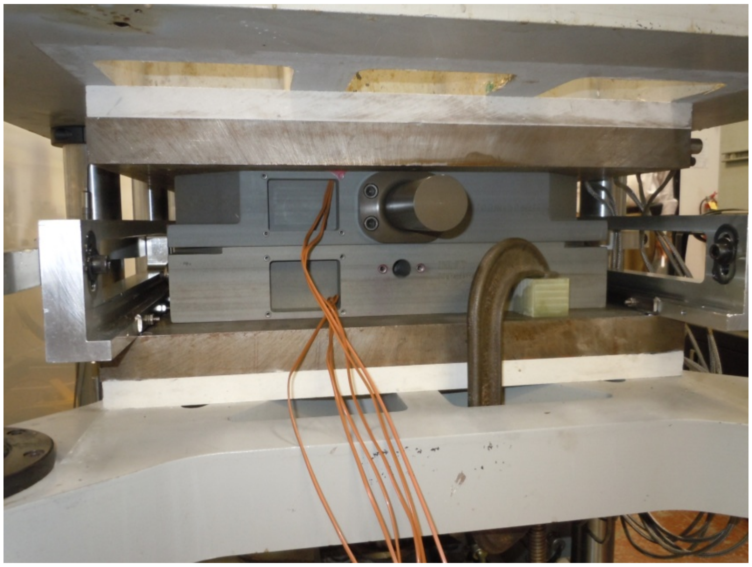


Figure 17 Showing Full Mold Closure Under Hydraulic Pressure

10.2.2 Tool Evacuation

Prior to resin injection, a vacuum was drawn to evacuate the mold. A vacuum check was performed to make sure there is no leak across the perimeter o-ring and at any of the resin injection or vacuum line connections.

10.2.3 Resin Injection

Once the required vacuum was established in the mold cavity, resin injection started. Once calibrated, the injection system was designed to consistently inject a set ratio of the two-part resin into the mold. The resin injection system is shown in **Figure 18**.

Figure 18 RTM Injection Machine

10.2.4 Cure Cycle

Once injection is completed, a preset cure cycle started which was determined from thermal survey performed earlier, which consisted of

- Ramp up to 175°F
- 1 hour dwell at 175°F
- Ramp up to 285°F
- 2 hour dwell at 285°F

The entire cure cycle took about 4.5 hours. The maximum spread of temperature readings at the 285°F dwell is from 276.7°F to 289.9°F. **Figure 19** shows the thermocouple data from the first injection. The data from the two subsequent part injections were similar.

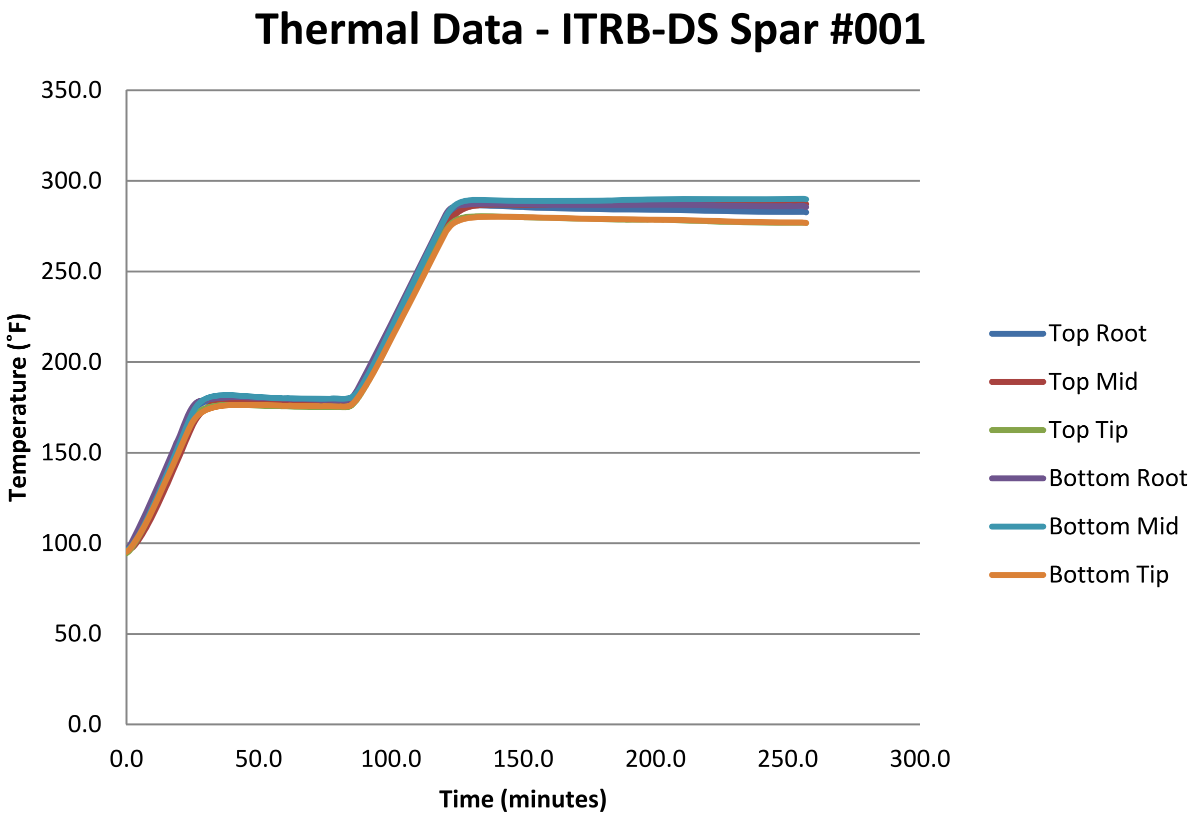


Figure 19 Thermo Data for Spar #001

10.2.5 Demold

The finished part was demolded at temperature to prevent the spar being crushed by the RTM mold due to CTE difference between metal and composite during cool down. All the tooling pieces separated without any issue.

10.3 SECONDARY OPERATIONS

Additional secondary work was completed for each spar. The operations included:

- NDI with both ultrasound and x-ray
- Contour inspection
- Machining and trimming
- Material testing on coupons Lug bushing installation
- Lug bushing ID boring
- Pitch horn installation
- Pitch bearings installation

10.4 INSPECTION AND TESTING

10.4.1 Visual Inspection

As a standard composite practice, all trimmed sections were inspected for fiber folds, delamination, porosity, fiber wet out, and fiber wash. Except for some minor porosity, the laminate generally looked very good.

10.4.2 Contour Inspection

Contour inspections were performed using Cobham CMM inspection arm as shown in **Figure 20** below with following procedures.

Figure 20 Portable Inspection Equipment

- Spars were fixtured by the root end only with the rest of the spar in free state.
- A set of alignment points was taken to orient spar with measurement software.
- Point clouds were taken at radial stations reference by drawing COBRP423000, Note 24.
- Point clouds were then overlayed against a 3D CAD model to measure deviation

Contour inspection of radial stations close to the root end was generally within drawing specification. However, results from free hanging part of the spar would require additional investigation as the spar in a free state bent slightly in both chordwise and spanwise directions.

10.4.3 NDI with both Ultrasound and X-ray

All three as molded spars underwent NDI testing. Since no reference standard or destructive testing were conducted to verify the NDI results, the results were for reference only. For ultrasound testing, both manual pulse-echo A-scan and through transmission C-scan were required due to part geometry. Typical c-scan ultrasound testing results are shown below.

Figure 21 shows typical sound signal transmission through a section of the spar.

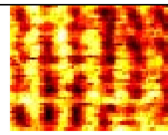


Figure 21 Typical Signal Transmission

Figure 22 shows attenuation of sound signal transmission through a section of the spar due to causes that would require additional investigation to identify and interpret.

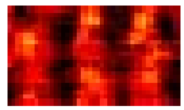


Figure 22 Typical Signal Attenuation

While ultrasound was used to check laminate quality, x-ray films were taken of the spars to check fiber orientation and structural integrity of the underlying components.

10.4.4 Material Testing on Coupons

Spar material coupons were sent out to Delsen Testing Laboratories, Inc. for material testing. The following tests were conducted as part of laminate quality evaluation.

Table 4 Spar Material Testing Matrix

Test	Test Method	No of Specimens
Fiber Volume / Porosity	ASTM D3171-11, Method 1, Procedure B	12
0° Tensile Str., Modulus Poisson's Ratio	ASTM D3039-08	6
0° Compressive Str., Modulus	ASTM D6641-09	6

Both fiber volume and porosity results met drawing requirements. Since there was no acceptance criteria for tensile and compressive strength, these results are for reference only. These tests, along with destructive visual and NDI tests performed, provided a complete understanding of laminate quality, which indicated a high quality laminate for spars fabricated under this program.

10.5 FINISHING OPERATIONS

10.5.1 Machining and Trimming

Machining and trimming of the spar were performed on all three spars using a Cobham designed fixture using the following procedure:

- Spars were rough trimmed on both ends

- Spars were mounted on the fixture
- CNC indicated spindle location
- Pilot holes were drilled first
- Then a helical interpolating machining program machined the final through holes.

In general, machining went very smoothly, no delamination or edge fiber breakout was observed. Fortunately, some of the concerns with machining a multi-material laminate didn't materialize.

10.5.2 Lug Bushing Installation

After machining the lug holes, the spars and lug bushings were sent to Boeing for lug bushing installation.

10.5.3 Lug Bushing ID Boring

With the lug bushing installed, spars were shipped back to Cobham. Cobham machined the ID of the lug bushing with a boring bar with the same machining fixture that was used for lug hole machining.

10.5.4 Pitch Horn Installation

Cobham bonded the pitch horn to pitch cuff region of the spar with film adhesive using the following process,

- Spar OML bonding surface was prepped and pitch ID surface was primed
- Film adhesive was applied to ID surface of pitch horn.
- Pitch horn is located onto the spar with a locating fixture.
- Fasteners were torqued to drawing specification to achieve appropriate bondline pressure.
- Then the entire assembly is transported to the oven for the full cure cycle.
- Locating fixture is removed from spar.

Prior to actual bonding, Cobham performed both a thermal survey and impression trial of the bond line following the process above to verify bondline temperature profile and bondline thickness. For the thermal survey, six TCs were inserted around the bondline surface between ID of pitch horn and OML of spar. For the impression test, film adhesive was sandwiched between layers of .001" release film. From the impression sample, bondline thickness was verified. The actual bonding cycles went very smoothly with uniform squeeze out along the perimeter of the bondline.

10.5.5 Pitch Bearings Installation

Pitch bearings press fit in accordance with Boeing drawings to complete the spar fabrication.

11. CONCLUSION

This program successfully completed the development and demonstration of a triaxially braided, RTM spar designed to meet ITRB requirements. The scope of the program included structural design, materials selection, manufacturing producibility analysis, tooling design and fabrication, triaxial braid preform development, fabrication and delivery of triaxial braided spar preforms, Resin Transfer Molding (RTM) process development and trials, and delivery of two (2) composite spars and one (1) destructive test spar. In addition, a set of production quality RTM tools was built and delivered. **Table 5**, below, summarizes the program Technical Performance Measure Assessment.

Table 5 Technical Performance Measures Assessment

TPMs	Verification Method	Assessment
Dimensional Requirements per COBRP423000-103 and -105 Mfg Demo Spar Assy Dwg:	Dimensional Inspection	Generally the spars are dimensionally compliant. There are a couple of minor discrepancies that can be easily fixed. Also, there are some manufacturing tolerances that need design reevaluation
Contour relative to cured condition Datum Structure	CMM	Key dimensional characteristics compliant
Alignment and diameter of Pitch Bearing journal surfaces to lug	Bore Gage for Diameter and Go-No-Go Gauge for alignment	Compliant prior to lug bushing installation
Installed Pitch Bearing diameters and alignment	Bore Gage for Diameter and Gauge for alignment	Outboard pitch bearing out of round by .005" after lug installation
Lug hole diameter prior to bushing installation	Bore Gage for Diameter	Compliant
Final Lug hole ID and alignment to Pitch Bearing journal surfaces	CMM	Compliant to inboard pitch bearing. Outboard pitch bearing out of round after lug bushing installation
Orientation of Lug Fitting to OML Contour datum structure at lug	CMM	Compliant prior to lug bushing installation
Alignment of SQ lug OML to Pitch Bearing journal surfaces	Dimensional Inspection	Not assessed
Position and alignment of Pitch Horn bushing axis to Pitch Bearing journal surfaces	CMM	Compliant to inboard pitch bearing. Outboard pitch bearing out of round after lug bushing installation
Position of Spar Pitch Horn OML diameter relative to Pitch	CMM	Compliant to inboard pitch bearing. Outboard pitch

Bearing journal surfaces		bearing out of round after lug bushing installation
Fiber placement angles within ±XX˚ of longitudinal Pitch Cuff and Spar axis as specified per COBRP423000-103 and -105 Mfg Demo Spar Assy Dwg (Note 7) verified by measuring pics/in (Note 11)	A&P In-Process Verification	Complete additional braiding process development and/or update drawings needs to be updated to reflect actual achievable angles and tolerances
No delamination, ply folds or wrinkles, fiber distortion or thru laminate tow gapping (Note 8 and 21)	Visual	Compliant
Capture mandrel component weight, mandrel assembly weight, preform + mandrel weight, and as-molded weight.	Weight scale	Compliant
Fiber Volume ≥XXX%	Coupon Testing	Compliant
Laminate porosity ≤XX%	Coupon Testing	Compliant
Visual and NDT Inspection meets HP15-90 criteria (Note 19)	Visual	Compliant
Contour Inspection	CMM	Line profile compliant after best fit. Overall profile requirement not compliant due to slight bending in the spanwise and chordwise direction
Bonded Pitch Horn Proof Load ≥XXX lbs prior to fastener installation	-	Compliant
Laminate strength meets minimum values as specified in Material Strength Requirements when demonstrated in accordance with recommended minimum Coupon Test Matrix	Coupon Testing	Testing completed. Minimum value not available for assessment
Triaxial braided RTM production tooling and process demonstrated	Visual inspection and test	Yes

12. LESSONS LEARNED

Cobham demonstrated the ability to manufacture the ITRB spar utilizing the RTM process. The development effort across the fabrication of three spars proved the design and processing baseline are repeatable and generally robust. Thorough design and development preparation yielded very solid fabrication results.

12.1 FOR TOOLING

Some improvements were identified that could be implemented for production representative tooling.

12.1.1 RTM Mold

- Attachment of root end mandrel to mandrel will need modification to improve tooling robustness
- Machine root end mandrel shoulder to account for pre trimmed pitch bearing retainer
    - Develop an improved method to keep pitch bearing retainer in place

12.1.2 Fixtures for Secondary Operations

- Investigate alternate approach to holding spar on machining fixture
- Improve tooling cart for RTM mold

12.2 PROCESS

- Some future process improvements had been identified

12.2.1 Braiding

- Improved end trimming at braider to minimized rework at spar fabricator
- Improve method for preform debulking

12.2.2 Inspection

- Develop NDI standards