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Research Article

Airfoil Surface Forming and Conformity Test Using Laser Tracker

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In this study, NACA0018 airfoil surface conformity test was conducted using API tracker3 in combination with SpatialAnalyzer (SA) and modeling software SolidWorks. Plaster of Paris is used as a plug making material and a woven-type fiberglass is used as mold and airfoil surface making material. For airfoil surface analysis, three-dimensional model of the airfoil surface was developed in SolidWorks software and imported in IGES file format to SpatialAnalyzer (SA) software. Then, measurements were taken from manufactured airfoil surface using laser tracker through surface scanning method. Surface conformity test was conducted through fitting of measured points to surface model imported from SolidWorks to SpatialAnalyzer (SA) software. The optimized fit summary result shows that the average fit difference is 0.0 having standard deviation from 0.22224 from the average and zero with RMS of 0.2210. The maximum magnitude of the difference including x and y together is 0.5336 and the minimum −0.5077. Thus, with a given range of surface quality specification, laser tracker is an easy and reliable measurement and inspection tool to be considered.

1. Introduction

Fiber reinforced composites (FRC) are now becoming the natural material selection for aerospace industry due to their large strength and stiffness to weight ratio compared with conventional structural materials [1]. With the features of high stiffness, strength, and low weight, the high-performance composites were extensively utilized not only in the aerospace industry, but also in marine, armor, automotive, and civil engineering applications [2]. An obvious advantage of fiber-reinforced composites over metals is the shape potential, particularly the ability to produce large double curvature geometry [3]. This shape potential ability of the FRC should be supported with appropriate measuring technologies for its shape and geometry conformity test, alignment, and assembly. Among these technologies, commercial laser trackers are the pioneer technology available for various applications.

A laser tracker is a portable device that makes three-dimensional measurements which is extremely appealing to metrology instruments for numerous reasons including size, portability, repeatability, accuracy, and ability to capture large volumes of 3-dimensional coordinate data quickly and in real-time [4]. Aerospace industry was an early adopter of laser tracker technology where large scale of metrology, involving in-place inspection of large parts and assemblies, is required. The automotive industry uses many similar tooling applications to those found in aerospace and can apply laser trackers to similar ends. Laser trackers are not just used for part inspection only; they are often used to monitor the condition of a fixture or tool over time and provide real-time feedback on the wear or movement of the fixture or tool [5]. Laser tracking system enables measuring three-dimensional coordinates based on the principle of trilateration with high accuracy. Laser-based instrument emits a laser from a gimbaled head (Figure 1); in the case of a laser tracker, a spherically mounted retroreflector (SMR) is then used to reflect the laser back to the unit allowing the distance to be measured [6].

Literature reveals the use of laser tracker as a reference instrument for articulated arm coordinate measuring machines (AACMMs) verification processes by [7], as a calibration system for a coordinate measuring machine (CMM) by [8], as a metrology tool for aligning optical systems, including the use of mirrors and windows by [9], and as an instrumentation tool used to make large scale measurements within aerospace assembly by [6]. Laser tracker technology applications in the manufacturing sector include machining equipment and tool alignments, inspection of parts, complex assembly of components, equipment, machine and tool calibrations, and data collection of dimensional information for reverse engineering of components with three-dimensional information to complete solid parametric models that can be used to manufacture [4, 10, 11]. The objective of this paper is to produce airfoil surface from fiber glass and use API laser tracker3 in combination with spatial software as surface conformity testing tool.

2. Methods and Materials

This paper covers surface forming of NACA0018 airfoil from fiberglass and conduct conformity test using laser tracker. Therefore, the procedure of experimental work starts with plug making, mold making, casting/surface forming, and conducting the conformity test. Table 1 shows a list of materials and their purpose to manufacture the airfoil.

Plug Making. The first step in fiberglass mold making is to make a plug which is typically a representation of the finished part and can be an actual part or a mockup of a part [12]. Plug is made from a variety of different materials which include, but are not limited to, wood, plaster, polyester resin, fiberglass, polyurethane foam, etc. [13]. For the purpose of this study, a white fine-grained plaster commonly known as *Plaster of Paris* is chosen as plug material due to it being readily available at constructional material stores, inexpensive, easy to use, able to take shape without shrinkage and crack, rapid cure, and being fairly strong for the required purpose. Figure 2 shows the schematic representation of plug forming process.

Since mold making requires use of a full-scale exact geometry of the product to fabricate, plug is assumed to be split pattern having exact shape of half side of the airfoil. Manual extrusion forming process with a movable extrusion die approach was adopted to shape plug as shown in Figure 2(a). A template that has the exact curvature of airfoil was made from sheet metal to represent movable extrusion die. The curvature was prepared using special sniper cutting tool and polished with fine grit sand paper. To guide the template along an edge of molding board in plug shaping process, a special fixture similar to try square was carefully glued at one end of the template as shown in Figure 2(b). To prevent flexing of the template, it is backed with rigid material made of metal bars. The fixture is prepared to have a smooth surface finish with two of its surfaces perpendicular to each other. Shaping process of the plug was done by gently sliding the template over properly mixed plaster with water over molding board using two hands. During the shaping process, the guiding plate enables the template to slide over the surface of molding board at equidistance from the edge of the molding board. The left-hand controls movement of the template across the boarding edge and the right-hand controls movement of the template over surface of the molding board.

To complete overall shaping of the plug, several rough shaping operations across the length were conducted. Finally, the plug shaping process was completed and the plug was allowed to dehydrate before use. After proper dehydration of the plug was confirmed, the surface was sealed to cover porosity of the plug with automotive body filler and sand finished at 220 grit size.

Mold Making. For the purpose of this study, 400gsm woven cloth type fiberglass was chosen as mold and airfoil material. Since the airfoil profile is symmetrical, both upper half and lower half mold have been made from the formed plug after one another. Before proceeding with mold making, the plug surface was finished up to the desired level and PVA was applied on the surface as the mold release and surface protection of finished plug for next use. Then, epoxy was prepared by mixing with catalyst and hardener at the recommended ratio. The prepared epoxy was then brushed on the surface of the plug and molding board surface at an equidistance of 40 mm from both sides of the plug. When the epoxy densification begins, settlement of fiber glass layers laid up took place as shown in Figure 3(a). This extra layup is used to make mold with flanged for bolting purpose as shown in Figure 3(b). After the layer was cured, 2 layers of the fiberglass were laid up at a time until the desired thickness achieved. Much layer was added on the flanged part to make the mold rigid. After the mold fully cured, the mold was removed from the plug, followed by trimming of excess laminates, corrections of defected surfaces, cleaning the mold, and finishing. For correcting defected surfaces, special polyester putty grey was used. The other half mold was similarly made from the same plug and prepared for assembly as shown in Figure 3(b).

Some of the precautions required in the mold making process are (1) to make the working area free of dust and dirt as the mold release may trap it and become part of the surface as it dries; (2) plug surface finish should be to the required quality and surface imperfection needs to be corrected as the surface seen on the plug is the surface finish obtained on the mold; (3) proper ratio of hardener and epoxy needs to be used as faster drying rate or lower drying rate affects mold quality; (4) proper wet-out of glass is required to avoid air bubbles which results in surface defect; and (5) proper pressure application is required to distribute epoxy uniformly over the plug so that surface defect due to wet problem can be minimized.

Airfoil Surface Forming. Before proceeding with airfoil surface forming, PVA was applied on the surface of the mold to facilitate release of the airfoil. The airfoil surface was made in two halves of the mold as shown in Figure 4(a). After the

Table 1: List of materials and their purpose.

S. no	Materials	Purpose
1	Molding board (surface plate covered with plastic)	Plug and mold making
2	Plug shaping template	Plug shaping
3	Plaster (plaster of Paris)	Plug making
4	PVA (polyvinyl alcohol)	Plastic film creating
5	Epoxy	Layup fiber glass
6	Fiberglass (400gsm woven cloth)	Mold and airfoil making
7	Methyl ketone	Hardener
8	Cobalt naphthenate	Catalyst
9	Black toner	Mold coloring
10	Acetone	Clean up tools

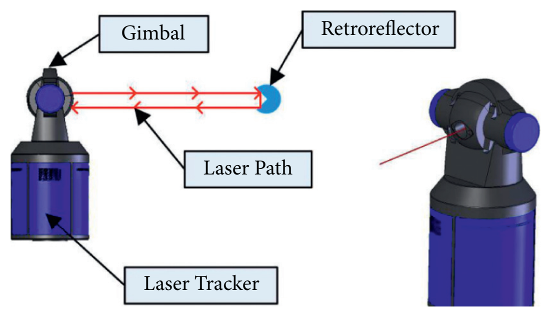
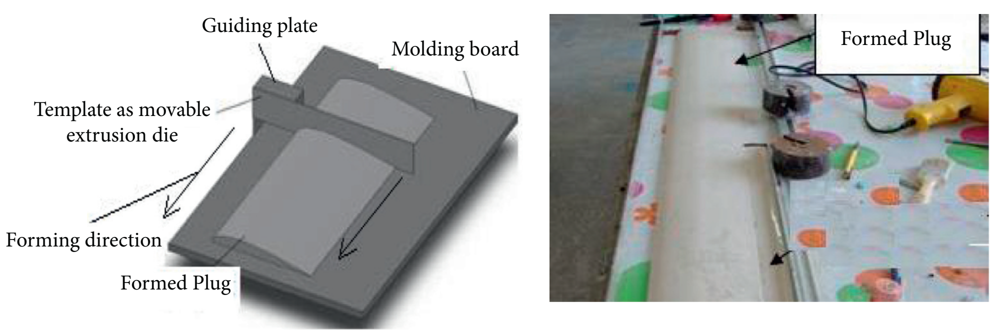


Figure 1: Laser tracker system [6].

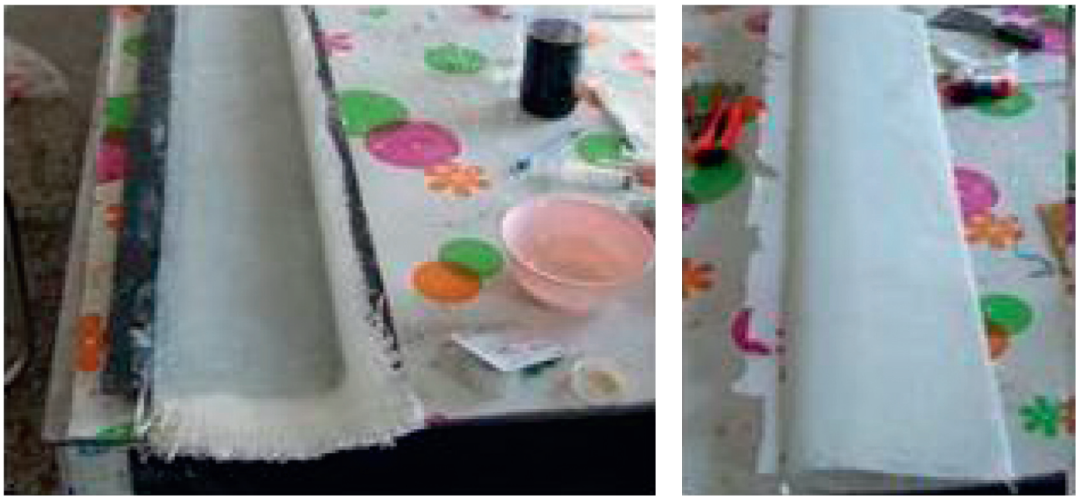


(a) (b)

Figure 2: Schematic representation of plug forming process.

(a) (b)

Figure 3: Mold making process. (a) Fiberglass layup. (b) Complete mold assembly.



(a) (b)

Figure 4: Airfoil surface forming. (a) Fiberglass layup. (b) Finished airfoil with excess material.

layup was finished and cured, excess portions were cut and the edges were prepared for assembly. After assembly, the two halves of the airfoil were then glued together from the inside at the leading and trailing edge using epoxy and fiberglass. The assembly was dismantled and a complete airfoil with excess materials at the parting line (Figure 4(b)) was removed from the mold. Excess materials were removed, defected surfaces were corrected using special polyester putty grey, and the surface was finished up to the required level.

Surface Conformity Testing. The API model used in the experimental testing was an API tracker3 in combination with SpatialAnalyzer (SA) software. As shown in Table 2, API tracker3 has angular accuracy of 3.5 μm/m, ADM accuracy of $\pm 15\,\mu$m, and IFM accuracy of $>\pm 0.5$ ppm. In this experiment, the laser tracker is located within the range of 4 m from the target point so that the correction point or deviation distance of the laser tracker from the target point would be plus or minus 0.5 μm. In the process of surface conformity test, flatness and linearity of the molding board were first checked. For this purpose, random measurements were taken from top surface of the molding board with tracker through scanning method of measurement taking as shown in Figure 5(a). The points were then fitted to make a plane to check the flatness of the molding board. For checking the linearity of the molding board edge, points were measured randomly along the edge as shown in Figure 5(b). A line was then fitted to the points for checking linearity. To check linearity of template movement along the edge of molding board in the process of mold making, *Spherically Mounted Retro Reflector* (*SMR)* was attached to the template to take reading while the template made shaping process of the plug. Surface flatness and linearity were then analyzed for the measured points using SpatialAnalyzer (SA) software.

To test surface conformity of the airfoil, one side of the whole length of the airfoil was divided into 15 equal sections. Then across each division line, measurements were taken along the chord length starting from leading edge toward tail through surface scanning method. To analyze the airfoil surface with measured points taken, airfoil design model was developed in SolidWorks software and imported in IGES file format to SpatialAnalyzer software. Figure 6 shows measured points using laser tracker and Figure 7 shows measured points imported to SpatialAnalyzer (SA) software.

3. Results and Discussion

Table 3 shows the measurements randomly taken at different points to check the flatness and linearity of the molding board. The points were chosen to fit a plane using Spatial Analyzer (SA) software. Accordingly, the flatness of the plane created using the points became 0.0386 with root mean square (RMS) of 0.0079. So, it can be generalized that the flatness of the molding board is equal to the flatness of this plane.

Table 4 shows the tracker reading taken along the edge of the molding board to check linearity. Checking the linearity is important as the edge is used to guide the template in the plug making process. The points were connected to fit line SpatialAnalyzer (SA) software. The linearity analyzed using the SpatialAnalyzer software indicates 0.2067 with RMS of 0.0908.

Table 4 shows the reading taken by *Spherically Mounted Retro Reflector* (*SMR)* attached to the template to take reading while the template makes shaping process of the plug. The measured points were fit to make a line to check linearity test of the movement in SpatialAnalyzer software and the result shows 0.2179 linearity with RMS of 0.0918. When we compare the linearity of the molding edge to the template movement along the molding edge, the result

Table 2: Commercial laser tracer specifications [9].

S. no	Model	Working range (m)	Angular accuracy	Distance accuracy (ADM)	Distance accuracy (IFM)
1	Leica LTD600	40	±25 μm	±25 μm	±10 μm ± 0.5 μm/m
2	Leica AT401	320	15 μm + 6 μm/m	±10 μm	±0.4 μm
3	Leica AT901	50/160	15 μm + 6 μm/m	±10 μm	±0.3 μm/m
4	Faro ion	30/40/55	20 μm + 5 μm/m	16 μm + 0.8 μm/m	4μm + 0.8 μm/m
5	Faro vantage	30/60/80	20 μm+5 μm/m	16 μm + 0.8 μm/m	
6	API tracker3	15/40/60	3.5 μm/m	±15 μm (1.5 ppm)	>±0.5 ppm
7	API radian	40/100/160	3.5 μm/m	±10 μm (1 ppm)	>±0.5 ppm
8	API omni 2	160/200	±18 μm + 5 ppm	±15 μm + 1.5 μm/m	

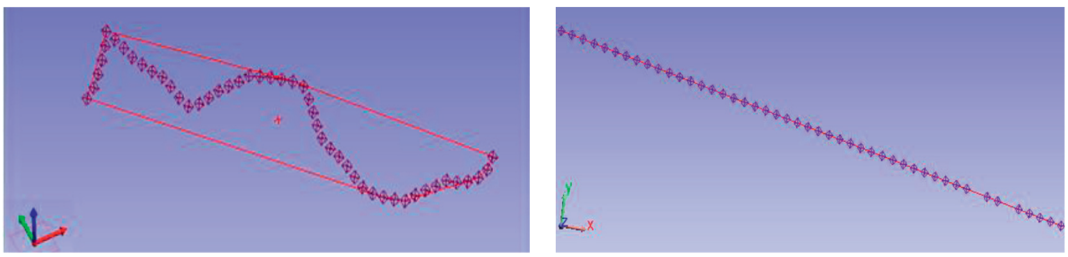

(a) (b)

Figure 5: Points measured on surface plate. (a) Measured on surface. (b) Measured on edge.

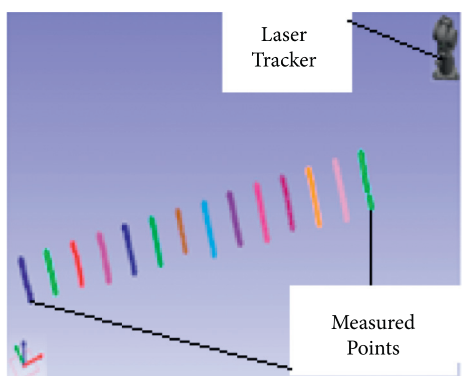


Figure 6: Laser tracker and measurement points.

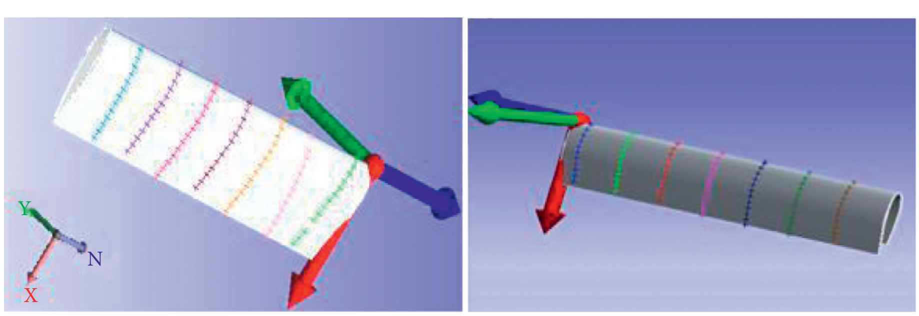


Figure 7: SpatialAnalyzer display of imported model.

shows linearity difference of 0.0112 with RMS difference 0.001. This proves that the template movement is almost parallel to the edge of the molding board without deflection from the molding board surface.

Table 5 shows the quick alignment points first selected and the optimization parameters of points to object fit. Table 6 shows the optimized fits of the points measured to the airfoil surface model imported from SolidWorks

Table 3: Tracker reading taken on top of molding board at different points.

Point group S plate top 48 points			
Point name	X	Y	Z
P1	−976.2759	−2140.5612	−481.2692
P2	−980.7335	−2152.6343	−481.1536
P3	−990.3482	−2161.4971	−481.0501
P4	−1002.4197	−2166.3966	−480.97
P5	1015.3528	−2168.9338	−480.9115
P6	−1028.0954	−2169.1193	−480.8853
P7	1039.5915	−2175.751	−480.7797
P8	1051.2279	−2180.9598	−480.6912
P9	−1062.93	−2186.9736	−480.5963
P10	−1074.0302	−2193.5324	−480.5214
P11	−1086.9986	−2194.064	−480.4546
P12	−1100.1986	−2193.6767	−480.4198
P13	−1113.294	−2192.2552	−480.3864
P14	−1125.9616	−2188.2754	−480.3779
P15	−1136.6008	−2180.2742	−480.4053
P16	−1146.6413	−2171.8494	−480.4606
P17	−1157.5336	−2164.7377	−480.4818
P18	−1168.7838	−2158.7666	−480.4981
P19	−1179.8543	−2150.9762	−480.5279
P20	−1187.1016	−2140.3997	−480.5796
P21	−1193.4046	−2129.0944	−480.6606
P22	−1199.829	−2118.0557	−480.7184
P23	−1207.6435	−2107.6629	−480.79
P24	−1221.0255	−2104.9024	−480.7788
P25	−1234.5046	−2104.706	−480.7413
P26	−1247.5803	−2104.92	−480.6895
P27	−1260.3825	−2105.782	−480.6336
P28	−1273.1835	−2107.0054	−480.5874
P29	−1284.4976	−2113.5615	−480.4824
P30	−1295.991	−2119.1133	−480.3963
P31	−1307.4492	−2125.1469	−480.3033
P32	−1318.0271	−2132.5771	−480.2127
P33	−1328.8502	−2139.4026	−480.1214
P34	−1341.2087	−2143.6695	−480.0521
P35	−1353.1007	−2137.2685	−480.0626
P36	−1364.4663	−2128.7971	−480.0957
P37	−1375.1794	−2121.4027	−480.127
P38	−1388.0924	−2117.9434	−480.1141
P39	−1400.971	−2113.3679	−480.1125
P40	−1413.037	−2108.683	−480.1131
P41	−1424.4997	−2101.7101	−480.1446
P42	−1435.7663	−2095.6768	−480.1587
P43	−1447.0337	−2089.7746	−480.17
P44	−1446.5152	−2102.7926	−480.0616
P45	−1448.6624	−2116.0266	−479.9442
P46	−1451.685	−2129.1464	−479.8188
P47	−1455.0269	−2141.7487	−479.706
P48	−1461.8059	−2152.6271	−479.5961
S plate 48-point fit plane			
Flatness		Measured	
RMS		0.0386	
		0.0079	

Table 4: Tracker reading taken on the edge of molding board.

Point group Template movement1			
Point name	X	Y	Z
P3	−913.8005	−2249.0049	−379.9377
P4	−926.466	−2247.0901	−379.8765
P5	−939.199	−2245.1128	−379.8617
P6	−951.938	−2243.1981	−379.8542
P7	−964.6058	−2241.1748	−379.822
P8	−977.3165	−2239.2531	−379.7737
P9	−989.937	−2237.3306	−379.7452
P10	−1002.5128	−2235.4107	−379.7243
P11	−1015.1814	−2233.4538	−379.6771
P12	−1027.916	−2231.491	−379.6557
P13	−1040.549	−2229.4971	−379.6318
P14	−1053.4084	−2227.3414	−379.62
P15	−1066.1477	−2225.359	−379.5878
P16	−1079.0193	−2223.4518	−379.571
P17	−1091.8151	−2221.4101	−379.5435
P18	−1104.4108	−2219.4773	−379.5111
P19	−1117.0033	−2217.5725	−379.4726
P20	−1129.634	−2215.6122	−379.4237
P21	−1142.2915	−2213.6537	−379.3974
P22	−1154.8561	−2211.6965	−379.3587
P23	−1167.4701	−2209.7026	−379.3317
P24	−1180.2329	−2207.6841	−379.3061
P25	−1192.8917	−2205.8501	−379.2798
P26	−1205.7916	−2203.8835	−379.283
P27	−1218.6228	−2201.8677	−379.2645
P28	−1231.2455	−2199.9227	−379.2504
P29	−1244.1254	−2197.9692	−379.2212
P30	−1256.8553	−2195.9994	−379.1809
P31	−1269.7158	−2194.0569	−379.1668
P32	−1282.3553	−2192.0388	−379.1503
P33	−1295.1198	−2190.0632	−379.114
P34	−1307.7332	−2188.1677	−379.0868
P35	−1320.3828	−2186.3373	−379.0773
P36	−1332.9954	−2184.4885	−379.05
P37	−1345.8163	−2182.4824	−379.0345
Template1 fit line			
Linearity		Measured	
RAM		0.2179	
		0.0918	

software to SpatialAnalyzer (SA). This table is the important or significant quantitative data that enables showing the difference between manufactured airfoil and the imported model. The fit summary result shows the average fit difference is 0. The standard deviation of the fit from the average and zero is 0.22224 with root mean square of 0.2210. The maximum magnitude of the difference including x and y together is 0.5336 and the minimum −0.5077. It can be generalized from this fitting that, considering error duplications from surface of molding board, template movement, and personal errors, and so on, the result indicates a good fit of the produced airfoil surface with the model created.

In the study conducted, the inspection result shows that the linearity of molding board edge and template movement is in agreement. That means the error that can be created due to template movement is very low. Concerning the quality of produced airfoil surface, based on the average value of the fitness of the measured points on the airfoil model created in SolidWorks, it revealed a good result from the RMS value.

Table 5: Quick alignment and optimization parameters.

Quick alignment (details)			
Quick alignment measurements			
Point name	Target offset	Deviation	
P11	19.0500	0.0278	
P11	19.0500	0.0021	
P11	19.0500	−0.0208	
P11	19.0500	−0.0047	
P7	19.0500	−0.0426	
P6	19.0500	0.0375	
Max dev.	0.0426		
RMS	0.0272		
Points to objects fit results (summary)			
Motion components expressed in frame A WORLD			
	X	Y	Z
Translation	0.5359	0.3122	−0.072
Rotation	0.0236	−0.05447	−4154
Optimization parameters			
Nominal drive	ON		
Drive to	0,0000	Weight	1.00
Low tolerance	OFF		
High tolerance	OFF		
Edge projection penalty	0,0000		

Table 6: Measurement between the measured points and model.

Vector group A::Query8-objectToProbe										
Name	Begin			End			Data			
	X1	Y1	Z1	X2	Y2	Z2	dX	dY	dZ	Mag
P1	6.4168	8.205	−653.472	6.5162	8.0386	−653.472	0.0994	−0.1663	0.0000	0.1938
P2	13.9589	11.1475	−652.182	14.03	10.8994	−652.182	0.0711	−0.2481	0.0000	−0.2581
P3	24.2189	13.0451	−651.2785	24.2352	12.9241	−651.2785	0.0183	−0.121	0.0000	−0.1224
P4	35.9082	14.5103	−650.5801	35.9323	14.2483	−650.5801	0.0241	−0.262	0.0000	−0.2631
P5	47.3456	15.1709	−649.9488	47.3562	14.7163	−649.9488	0.0105	−0.4546	0.0000	−0.4547
P6	58.9972	15.0377	−648.8608	58.9808	14.6609	−648.8608	−0.0163	−0.3767	0.0000	−0.3771
P7	70.7413	14.2066	−648.6646	70.6927	13.7012	−648.6646	−0.0485	−0.5054	0.0000	−0.5077
P8	83.5817	12.9057	−648.9153	83.5488	12.5719	−648.9153	−0.0329	−0.3338	0.0000	−0.3354
P9	96.1929	11.632	−648.8642	96.1485	11.2313	−648.8642	−0.0444	−0.4008	0.0000	−0.4032
P10	108.2623	10.0347	−648.86	108.236	9.8455	−648.86	−0.0269	−0.1892	0.0000	−0.1911
P11	120.881	8.255	−648.5069	120.862	8.1334	−648.5069	−0.0193	−0.1217	0.0000	−0.1232
P1	6.8597	8.4614	−552.4709	6.9583	8.2855	−552.4709	0.0986	−0.1759	0.0000	−0.2016
P2	14.5226	11.3032	−551.7133	14.5618	11.1561	−551.7133	0.0392	−0.1472	0.0000	−0.1523
P3	25.1348	13.1832	−551.7282	25.1196	13.2848	−551.7282	−0.0152	0.1016	0.0000	0.1027
P4	38.5944	14.572	−552.144	36.5903	14.6186	−552.144	−0.0041	0.0466	0.0000	0.0468
P5	48.0546	15.1858	−551.6777	48.052	15.3259	−551.6777	−0.0028	0.1401	0.0000	0.1401
P6	59.615	15.0099	−550.7785	59.6242	15.209	−550.7785	0.0092	0.1991	0.0000	0.1993
P7	71.624	14.1206	−550.4777	71.6337	14.2195	−550.4777	0.0098	0.0989	0.0000	0.0994
P8	84.4493	12.8203	−550.1964	84.4726	13.0578	−550.1964	0.0233	0.2375	0.0000	0.2387
P9	96.9282	11.5497	−549.5392	96.9523	11.7624	−549.5392	0.0241	0.2127	0.0000	0.2141
P10	109.067	9.921	−549.7031	109.109	10.2225	−549.7031	0.0423	0.3015	0.0000	0.3044
P11	121.5449	8.1489	−548.9373	121.584	8.3911	−548.9373	0.039	0.2422	0.0000	0.2453
P12	134.1472	6.0297	−549.0643	134.152	6.0627	−549.0643	0.0052	0.033	0.0000	0.0334
P1	6.9291	8.5001	−449.5712	6.6703	8.9667	−449.5712	−0.2588	0.4888	0.0000	0.5336
P2	6.7619	8.4062	−451.6719	6.5953	8.699	−451.6719	−0.1665	0.2929	0.0000	0.3369
P3	14.4468	11.2829	−450.8709	14.3976	11.4657	−450.8709	−0.0492	0.1828	0.0000	0.1893
P4	24.8174	13.1356	−450.0344	24.7722	13.4359	−450.0344	−0.0451	0.3003	0.0000	0.3037
P5	36.4938	14.5631	−449.3494	36.4754	14.7709	−449.3494	−0.0184	0.2078	0.0000	0.2086
P6	48.1703	15.1879	−449.0492	48.1666	15.3893	−449.0492	−0.0037	0.2014	0.0000	0.2014

Table 6: Continued.

Name	Begin			End			Data			
	Vector group A::Query8-objectToProbe									
	X1	Y1	Z1	X2	Y2	Z2	dX	dY	dZ	Mag
P7	59.6527	15.0082	−448.3468	59.6626	15.2198	−448.3468	−0.0098	0.2116	0.0000	0.2116
P8	71.5381	14.1291	−448.5351	71.5476	14.2252	−448.5351	0.0095	0.0961	0.0000	0.0966
P9	84.6755	12.7981	−448.9603	84.7039	13.0874	−448.9603	0.0284	0.2894	0.0000	0.2907
P10	97.2021	11.5185	−449.1652	97.2261	11.7288	−449.1652	0.024	0.2103	0.0000	0.2117
P11	109.5301	9.8563	−449.2984	109.579	10.2086	−449.2984	0.049	0.3523	0.0000	0.3557
P12	121.9032	8.091	−449.1445	121.952	8.3919	−449.1445	0.0489	0.3009	0.0000	0.3049
P13	134.4956	5.975	−448.0162	134.463	5.7674	−448.0162	−0.0324	−0.2076	0.0000	−0.2101
P1	7.0145	8.5471	−353.3182	6.9186	8.7223	−353.3182	−0.0959	0.1752	0.0000	0.1997
P2	14.6786	11.3444	−352.4545	14.6447	11.4741	−352.4545	−0.0339	0.1297	0.0000	0.134
P3	25.3276	13.212	−352.2393	25.2786	13.5412	−352.2393	−0.0491	0.3292	0.0000	0.3328
P4	36.7539	14.5859	−352.9306	36.7375	14.7743	−352.9306	−0.0164	0.1884	0.0000	0.1891
P5	48.2791	15.1899	−353.7939	48.2753	15.4083	−353.7939	−0.0038	0.2184	0.0000	0.2184
P6	59.8084	15.0009	−353.5183	59.8177	15.1975	−353.5183	−0.0093	0.1966	0.0000	0.1969
P7	71.6373	14.1197	−352.3211	71.6392	14.1805	−352.3211	0.006	0.0608	0.0000	0.0611
P8	84.7239	12.7933	−352.2928	84.7422	12.9798	−352.2928	0.0183	0.1865	0.0000	0.1874
P9	97.283	11.5093	−352.259	97.2892	11.5636	−352.259	0.0062	0.0543	0.0000	0.0547
P10	109.4294	9.8703	−352.2745	109.444	9.9773	−352.2745	0.0149	0.1069	0.0000	0.108
P11	121.7571	8.1147	−352.0612	121.759	8.1244	−352.0612	0.0016	0.0097	0.0000	0.0098
P12	134.3745	5.994	−350.3989	134.373	5.9838	−350.3989	−0.0016	−0.0102	0.0000	−0.0103
P1	6.9432	8.5079	−250.9592	7.0383	8.3362	−250.9592	0.095	−0.1717	0.0000	−0.1962
P2	14.6779	11.3442	−250.0998	14.7558	11.0463	−250.0998	0.0779	−0.2979	0.0000	−0.3079
P3	25.5328	13.2426	−250.5506	25.5494	13.1309	−250.5506	0.0166	−0.1116	0.0000	−0.1129
P4	37.1337	14.6185	−251.5869	37.1512	14.4124	−251.5869	0.0175	−0.2061	0.0000	−0.2068
P5	48.6337	15.1957	−252.3177	48.6374	14.9562	−252.3177	0.0037	−0.2395	0.0000	−0.2395
P6	60.3144	14.9763	−251.9501	60.2988	14.6638	−251.9501	−0.0155	−0.3125	0.0000	−0.3129
P7	72.0545	14.0779	−251.7314	72.0213	13.7449	−251.7314	−0.0332	−0.333	0.0000	−0.3347
P8	84.9526	12.7709	−252.5665	84.9453	12.6961	−252.5665	−0.0073	−0.0748	0.0000	−0.0751
P9	97.2943	11.508	−252.0001	97.2926	11.4926	−252.0001	−0.0018	−0.0154	0.0000	−0.0155
P10	109.7183	9.8302	−251.3593	109.736	9.9584	−251.3593	0.0178	0.1281	0.0000	0.1294
P11	121.8731	8.0959	−250.4138	121.897	8.243	−250.4138	0.0239	0.1471	0.0000	0.149
p1	7.1282	8.6089	−149.5018	7.2926	8.3033	−149.5018	0.1644	−0.3055	0.0000	−0.347
p2	14.8982	11.401	−149.1145	14.942	11.2287	−149.1145	0.0438	−0.1723	0.0000	−0.1778
p3	25.7702	13.2777	−148.885	25.7617	13.3325	−148.885	−0.0085	0.0574	0.0000	0.0581
p4	37.5277	14.6514	−149.1094	37.5283	14.6439	−149.1094	0.0006	−0.0075	0.0000	−0.0075
p5	49.1748	15.2031	−1487358	49.1737	15.2938	−148.7358	−0.0011	0.0907	0.0000	0.0907
p6	61.4617	14.9161	−148.3716	61.4625	14.9311	−148.3716	0.0008	0.015	0.0000	0.015
p7	73.2102	13.9613	−149.9501	73.1985	13.8464	−149.9501	−0.0117	−0.1149	0.0000	−0.1155
p8	86.0039	12.668	−150.7379	86.0056	12.6851	−150.7397	0.0017	0.0171	0.0000	0.0172
p9	98.4956	11.3678	−149.9477	98.4843	11.2729	−149.9477	−0.0113	−0.0949	0.0000	−0.0955
p10	110.7626	9.6868	−150.3907	110.746	9.5677	−150.3907	−0.0162	−0.119	0.0000	−0.1201
p11	122.8961	7.9281	−150.4629	122.843	7.6097	−150.4629	−0.05227	−0.3184	0.0000	−0.3227
p1	7.2393	8.6681	−53.4578	7.266	8.6176	−53.4578	0.0267	−0.0505	0.0000	−0.0572
p2	15.1676	11.4684	−52.7572	15.1699	11.4593	−52.7572	0.0022	−0.0091	0.0000	−0.0094
p3	25.9821	13.309	−51.8935	25.9649	13.4261	−51.8935	−0.0172	0.1171	0.0000	0.1184
p4	37.4761	14.6472	−51.3118	37.4772	14.6347	−51.3118	0.001	−0.0125	0.0000	−0.0125
p5	48.8743	15.1992	−50.8644	48.8732	15.279	−50.8644	−0.0011	0.0798	0.0000	0.0798
p6	60.5072	14.9666	−51.0764	60.5139	15.0984	−51.0764	0.0067	0.1317	0.0000	0.1319
p7	72.4603	14.0373	−51.0059	72.4632	14.0669	−51.0059	0.003	0.0296	0.0000	0.0297
p8	84.9583	12.7703	−53.4538	84.96.37	12.8251	−53.4538	0.0054	0.0547	0.0000	0.055
p9	97.4301	11.4924	−54.3137	97.4212	11.4158	−54.3137	−0.0088	−0.0766	0.0000	−0.0771
p10	109.7973	9.8193	−55.489	109.786	9.7359	−55.489	−0.0115	−0.0834	0.0000	−0.0842
p11	121.9352	8.0858	−54.4688	121.87	7.6837	−54.4688	−0.0653	−0.4021	0.0000	−0.4073

All vectors summary: Vector GroupA: : Query8-objectToProbe

Statistic	Dx	dy	Dz	Mag
Min	−0.2588	−0.5054	0.00	−0.5077
Max	0.1644	0.4666	0.00	0.5336

Table 6: Continued.

Name	Vector group A::Query8-objectToProbe									
	Begin			End			Data			
	X1	Y1	Z1	X2	Y2	Z2	dX	dY	dZ	Mag
Average	0		0			0.00			−0.0001	
StdDev from avg	0.0519		0.2163			0.00			0.2224	
StdDev from zero	0.0519		0.2163			0.00			0.2224	
RMS	0.0516		0.2149			0.00			0.221	
Tol range									−0.762	
									0.762	
In tol									81(100.0%)	
Out tol										
Count	81									

From the above result, it is possible to conclude that fitting of measured points taken by laser tracker to surface of a model created in SolidWorks imported to SpatialAnalyzer software can be used as an inspection tool against a given specification. Various applications of a laser tracker have been discussed in [7–9]. The use of a laser tracker as instrumentation tool and inspection tool is in agreement with [4–6, 11]. A comparison of commercial metrology instruments conducted by [6] on Metris K610, Metris MV224, Faro tracker, and V-stars shows the ability of laser tracker to work in higher working range within the same level of uncertainty with compared instruments.

4. Conclusions

A laser tracker was chosen as an inspection tool to study the surface conformity test of airfoil surface. The following conclusions were drawn from the current work:

(i) Measurements are taken from the airfoil surface using laser tracker through surface scanning method and these measured points are fitted to three-dimensional surface model imported to SpatialAnalyzer software

(ii) From the test results, effect of error coming from the molding board flatness and linearity is negligible. Effect of manual shaping of the plug also is considered negligible

(iii) From the surface conformity test, since the measured points are perfectly fitted with three-dimensional surface model created, the manufactured product quality is good

(iv) It is also confirmed that laser tracker is one of the important measurements and inspections that can be easily utilized within the acceptable range of accuracy

Data Availability

For airfoil surface analysis, three-dimensional model of the airfoil surface was developed in SolidWorks software and imported in IGES file format to SpatialAnalyzer (SA) software. Then, measurements were taken from the manufactured airfoil surface using laser tracker through surface scanning method. Surface conformity test was conducted through fitting of measured points to surface model imported from SolidWorks to SpatialAnalyzer (SA) software.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] J. Zangenberg, P. Brøndsted, and M. Koefoed, "Design of a fibrous composite preform for wind turbine rotor blades," *Materials & Design*, vol. 56, pp. 635–641, 2014.

[2] J. L. Tsai, B. H. Huang, and Y. L. Cheng, "Enhancing fracture toughness of glass/epoxy composites for wind blades using silica nano-particles and rubber," *Procedia Engineering*, vol. 14, pp. 1982–1987, 2011.

[3] K. L. Edwards, "An overview of the technology of fibre-reinforced plastics for design purposes," *Materials and Design*, Elsevier, vol. 19, , pp. 1–10, 1998.

[4] "Prime Machine Inc. Laser Measurement and Data Analysis," 2019, https://lasertracker.com/%20date%20explore.

[5] I. Wright, "Laser Trackers – from Inspection to Manufacturing," 2016, https://www.engineering.com/AdvancedManufacturing/ArticleID/13499/Laser-Trackers-From-Inspection-to-Manufacturing.aspx.

[6] J. E. Muelaner and P. G. Maropoulos, "Large Scale Metrology in Aerospace Assembly," in *Proceedings of the 5th International Conference on Digital Enterprise Technology (IN DET)*, Nantes France, October 2008.

[7] R. Acero, A. Brau, J. Santolaria, M. Pueo, and C. Cajal, "Evaluation of the use of a laser tracker and an indexed metrology Platform as Gauge Equipment in Articulated Arm Coordinate Measuring Machine Verification Procedures," *Procedia Engineering*, vol. 132, pp. 740–747, 2015.

[8] K. Umetsu, R. Furutnani, S. Osawa, T. Takatsuji, and T. Kurosawa, "Geometric calibration of a coordinate measuring machine using a laser tracking system," *Measurement Science and Technology*, vol. 16, no. 12, pp. 2466–2472, 2005.

[9] J. H. Burge, P. Su, C. Zhao, and T. Zobrist, "Use of a Commercial Laser Tracker for Optical Alignment," in *Proceedings of the Optical System Alignment and Tolerancing*, San Diego, CA, USA, August 2007.

[10] "Basic fiber glass mold making," 2019, http://www.apitechnical.com/Downloads/2012/T3-Brouchure.pdf.
[11] H. Meagher, "Tools & Technology, Why Laser Trackers for 3D Precision Measurement?," 2014, http://www.oasisalignment.com/blog/laser-trackers-3d-precision-measurement/.
[12] "Fiberglass Mold Making- Plugs," http://miscellaneous/How_To_Resources/Fiberglass_Mold_Making_an_Intr/fiberglass_mold_making_an_introduction_to_plugs.html.
[13] S. Jones, "One Piece Fiberglass Mold Construction," 2009, http://www.fiberglassmoldmanual.com/download/SampleMoldManual.pdf©.