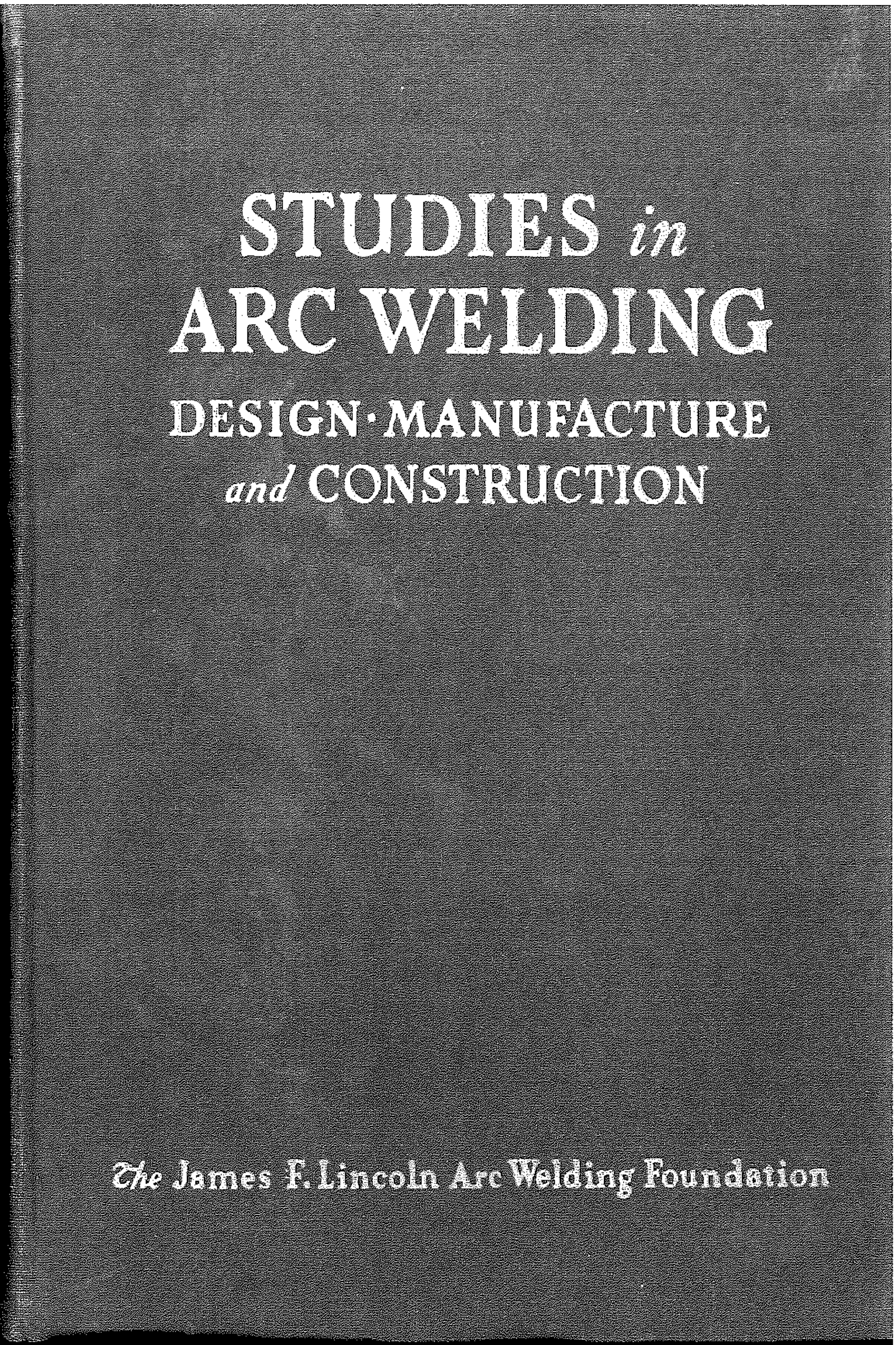

# STUDIES *in* ARC WELDING

## DESIGN · MANUFACTURE *and* CONSTRUCTION

*The* James F. Lincoln Arc Welding Foundation

NORTHROP, JOHN K., President, Northrop Aircraft, Inc., Hawthorne, Calif., co-author with Vladimir H. Pavlecka. Joint award: $3,700. Title of paper: "Arc Welding of Magnesium Aircraft Structures." See Section II, page 132.

OGDEN, JOHN O., General Manager and Director, Welded Products, Pty. Ltd., Sydney, Australia. Co-author with E. J. Eldridge; see above.

PAVLECKA, VLADIMIR H., Chief of Research, Northrop Aircraft, Inc., Hawthorne, Calif. Co-author with John K. Northrop; see above.

PETERSON, H. B., American Can Company, San Francisco, Calif. Award: $500. Title of paper: "Arc Welding in Automatic Can-Testing Machine." See Section IX, page 1203.

PRIEST, H. MALCOLM, Engineer, U. S. Steel Corp., Subsidiaries, Pittsburgh, Pa. Award: $2,700. Title of paper: "Welded Design of 250-Ton Flat Car." See Section III, page 228.

REISS, ERNEST, General Manager and Partner, The Art Chrome Company of America, Boston, Mass. Award: $3,700. Title of paper: "Arc Welding of Plated Tubular Furniture." See Section VI, page 507.

RENN, ALAN C., Assistant Foreman in Charge of Arc Welding, Vultee Aircraft, Inc., Vultee Field Division, Vultee Field, Calif. Award: $100. Title of paper: "Arc Welded Tubular Fuselage." See Section II, page 178.

RIORDAN, JOHN M., Chief Engineer, Bonnar-Vawter Fanform Co., Cleveland, Ohio. Award: $500. Title of paper: "Collating Machine of Improved Design." See Section IX, page 1244.

ROGER, JOHN P., Plant Engineer, The Babcock and Wilcox Co., Barberton, Ohio. Award: $150. Title of paper: "Welding a Locomotive Boiler." See Section III, page 214.

ROGERS, GEORGE B., General Contractor, Lakewood, Ohio. Co-author with Lawrence C. Blazey; see above.

ROSSMANN, PETER F., Chief of Miscellaneous Developments Research, Research Laboratory, Curtiss-Wright Corporation, Airplane Division, Buffalo, N. Y. Joint award: $1,500. Title of paper: "Welding Aircraft Engine Mounts Economically." See Section II, page 111.

RUTTEN, WALTER, Partner and Factory Superintendent, Railoc Company, Plainfield, Ill. Award: $250. Title of paper: "Production Machine for Domed Silo Roofs." See Section IX, page 764.

SALK, CLIFFORD A., Carman, Great Northern Railway, St. Cloud Shops, St. Cloud, Minn., co-author with Ray F. Theisen. Joint award: $250. Title of paper: "Arc Welded Conversion of Tenders Into Tank Cars." See Section III, page 247.

SAXE, VAN RENSSELAER P., Consulting Engineer, Baltimore, Md. Award: $700. Title of paper: "Welded Airplane Hangar." See Section V, page 343.

SCHEYER, EMANUEL, Assistant Designing Engineer, Designs Division, Board of Transportation, New York, N. Y. Award: $1,500. Title of paper: "Welded Steel Bents for Subways." See Section V, page 470.

SHEFELTON, W. E., Production Manager, R. D. Cole Manufacturing Co., Newnan, Ga. Award: $500. Title of paper: "Welded Lining of Horizontal Processing Tanks." See Section IX, page 1225.

SHIMKIN, B. M., Master Science Civil Engineer and Civil Engineer and Associate Bridge Designer Engineer, Bridge Department of State of California, Sacramento, Calif. Award: $250. Title of paper: "Trusses for Swing Bridge." See Section V, page 414.

SIMPSON, HOWARD W., Chief Engineer, Detroit Harvester Co., Detroit, Mich. Award: $700. Title of paper: "Arc Welding in the Manufacture of Mowers." See Section IX, page 1145.

SLAGHT, W. W., Chief Engineer, Cleveland Steel Products Corp., Cleveland, Ohio. Award: $250. Title of paper: "Universal Joint Drive Shafts." See Section I, page 24.

# The $200,000 Industrial Progress Award Program

The 1940-42 Progress Program was the second activity of The James F. Lincoln Arc Welding Foundation to encourage scientific progress of arc welding. It offered 458 awards.

The following information regarding awards is quoted from the Rules and Conditions governing participation in the Program:

"The 458 awards are grouped as follows:

"184 Divisional Awards:—1st, 2nd, 3rd and 4th awards of $700, $500, $250 and $150 respectively, in each of 46 Divisions.

"48 Classificational Awards:—1st, 2nd, 3rd and 4th awards of $3,000, $2,000, $1,000 and $800 respectively, in each of 12 Classifications.

"3 Main Program Awards:—1st, 2nd and 3rd awards of $10,000, $7,500 and $5,000 respectively.

"223 Additional Awards for Honorable Mention:—Awards of $100 each for 223 papers which do not share in any other award but which, in the opinion of the Jury of Award, deserve Honorable Mention. These 223 awards may be made for papers in any of the Divisions.

"The 184 Divisional Awards will be determined first. Then, from the papers receiving the 1st, 2nd, 3rd and 4th Divisional Awards in each Division of a particular Classification, papers will be selected to receive the 1st, 2nd, 3rd and 4th Classification Awards of the particular Classification, repeating the process for each Classification. From the Classificational award papers, papers will be selected to receive the 1st, 2nd and 3rd Main Program Awards. After the Divisional, Classificational and Main Program Awards have been determined, papers will be selected to receive the Honorable Mention Awards.

"For the paper selected as the best of all papers submitted, a 1st Grand Award of $13,700 will be made, composed of $700 as 1st Divisional Award, $3,000 as a 1st Classificational Award and $10,000 as 1st Main Program Award.

## Subject Matter of Papers in the $200,000 Industrial Progress Award Program

The following definitions of subject matter for papers in the Progress Program are quoted from the Rules and Conditions of the Foundation governing participation:

"Papers are to be on the subject, *progress made by application of arc welding between January 1st, 1940, and June 1st, 1942.* The paper shall cover progress on but one of the following points:

"(a) Redesign and manufacture or construction of an existing machine, structure, building, manufactured or fabricated product of ferrous or nonferrous metals, within the limits of the rules hereinafter prescribed, which was previously made in some other way and redesigned so that arc welding may be applied, in whole or in part, to its manufacture, fabrication or construction.

"(b) New design and manufacture or construction of a machine, structure, building, manufactured or fabricated product of ferrous or nonferrous metals, within the limits of the rules hereinafter prescribed, which was not previously made but which has been designed in whole or in part for the use of arc welding, the description to show how a useful result, which was impractical with other methods of construction, or could be better done by arc welding, is accomplished.

"(c) Organizing, developing and conducting a welding service. The welding service to be described in the papers may be conducted by Commercial Welders or Job Shops (G-1), Garages or Service Stations (G-2), Commercial Welderies (I-1), or Plant Welderies (I-2).

"(d) Developing, planning and performing maintenance or repair work with arc welding. The maintenance or repair work to be described in the papers may be Plant and Construction machinery and mechanical equipment of all kinds; also mobile equipment such as fleets of trucks, buses and taxicabs (L-1); or Structures and other structural applications of arc welding in maintenance (L-2), such as pipe lines, railroad tracks, bridge strengthening, and other such work, not covered under L-1.

"Note that the machine, structure, building, manufactured or fabricated product under (a) or (b) may be designed either in whole or in part for the use of arc welding.

"To qualify as to subject matter, the welding service as in (c) and the maintenance work as in (d), within the period January 1, 1940, to June 1, 1942, must have been either:

(1), planned and put into practice within the period;
or (2), put into practice within the period as result of plans made prior to the period.

Papers of otherwise equal merit will be preferentially rated in the above order.

## Requirements As to Submission of Papers

"1. Paper shall be submitted in two copies, one signed, the other unsigned.

"2. Each copy shall be enclosed in a separate sealed envelope.

"3. THE SIGNED COPY:—The signed copy shall have the following information written on the cover or title page and on the outside of the envelope in which it is enclosed:

Name, address and signature of the author, or authors.

Name and address of company with which author is connected.

Relationship between the author, or authors, and the company or concern.

Classification of the paper, as for example A-1, C-4, J-6, K-7, L-2, etc., depending upon the nature of the subject matter.

Name of individual or individuals to whom award check is to be made payable, and address of individual to whom it is to be mailed, if award is made for the paper.

A statement that data on the three Factors of Judgment are given in the paper.
A statement that cost data are given.
A statement that the work treated in the paper was carried on within the period—January 1st, 1940 to June 1st, 1942.
If paper may not be published, a statement to that effect.
If product, structure, or work used as subject is patented, a statement to that effect giving the full name and address of the person, or persons, from whom information regarding the patent is to be obtained.

"4. THE UNSIGNED COPY:—The unsigned copy shall have the following information written on the cover sheet and on the outside of the envelope in which it is enclosed:
Classification of the paper, as A-1, C-4, J-6, etc.
NOTE: On this unsigned copy of the paper and envelope no name or data other than classification are to be given.

"5. The two separate sealed envelopes, one containing the signed and the other the unsigned copy of the paper, are to be placed together in a large envelope, postage prepaid, and addressed: 'Secretary, The James F. Lincoln Arc Welding Foundation, P. O. Box 5728, Cleveland, Ohio,' and mailed, postmarked not later than midnight June 1st, 1942, and received in Cleveland not later than midnight July 1st, 1942.
Upon receipt thereof in Cleveland, the sender will be notified by mail.

"*Confidential Handling of Papers*—When received by the Secretary, the envelope in which both copies of the paper are enclosed will be opened and immediately the same identifying number will be given to the envelope containing the signed paper and the envelope containing the unsigned paper. The envelope containing the signed paper will be retained by the Secretary unopened and confidential. The envelope containing the unsigned paper, with the number identifying the author, and the classification and division for which the paper is entered, will be delivered, unopened, to the Jury of Award, with other contesting papers, at the close of the Program.

"The object will be to keep each paper confidential, without disclosure, until the Jury of Award considers the identified but unsigned paper. When the award papers are selected by the Jury of Award, proper certificate thereof will be made to the Foundation and then each award paper will be identified with its original paper on file with the Secretary."

Only papers contained in envelopes postmarked not later than June 1, 1942, and received in Cleveland not later than July 1, 1942, were accepted.

By letter of July 28, 1942, the Jury of Award of The James F. Lincoln Arc Welding Foundation certified to the Secretary its decisions concerning papers submitted in the Progress Program. The certification of papers, (See page xxv), was by number in accordance with the Rules of Award.

Upon receipt of the Jury's report, the Secretary and Assistant Secretary of the Foundation, identified the authors of the award-winning papers by reference to the various records.

# Industrial Classifications and Subject Divisions of the $200,000 Progress Program

The Progress Program was divided into 12 industrial classifications covering 46 subject divisions as given below:

| Industrial Classification | Subject Divisions |
|---|---|
| A AUTOMOTIVE | A-1 Engines |
| | A-2 Bodies |
| | A-3 Frames |
| | A-4 Trailers |
| B AIRCRAFT | B-1 Engines |
| | B-2 Fuselages |
| C RAILROAD | C-1 Locomotives |
| | C-2 Freight Cars |
| | C-3 Passenger Cars |
| | C-4 Locomotive and Car Parts |
| D WATERCRAFT | D-1 Commercial and Naval |
| | D-2 Pleasure |
| E STRUCTURAL | E-1 Buildings and Similar Structures |
| | E-2 Bridges |
| | E-3 Houses |
| | E-4 Miscellaneous |
| F FURNITURE and FIXTURES | F-1 House |
| | F-2 Office |
| G COMMERCIAL WELDING | G-1 Commercial Welders or Job Shops |
| | G-2 Garages or Service |
| H CONTAINERS | H-1 Contents Stationary (tanks, etc.) |
| | H-2 Contents Moving (pipe lines, etc.) |
| I WELDERIES | I-1 Commercial Welderies |
| | I-2 Plant Welderies |
| J FUNCTIONAL MACHINERY | J- 1 Metal Cutting |
| | J- 2 Metal Forming |
| | J- 3 Electrical |
| | J- 4 Prime Movers |
| | J- 5 Conveying |
| | J- 6 Pumps and Compressors |
| | J- 7 Business |
| | J- 8 Functional Machinery not otherwise classified |
| | J- 9 Jigs and Fixtures |
| | J-10 Parts of Functional Machinery |
| K INDUSTRY MACHINERY | K- 1 Processing |
| | K- 2 Construction |
| | K- 3 Petroleum |
| | K- 4 Steel Making |
| | K- 5 Farming |
| | K- 6 Household |
| | K- 7 Food Making |
| | K- 8 Textile and Clothing |
| | K- 9 Printing |
| | K-10 Industry Machinery not otherwise classified |
| L MAINTENANCE | L-1 Plant and Construction machinery and mechanical equipment of all kinds; also mobile equipment such as fleets of trucks, buses and taxicabs. |
| | L-2 Structures and other applications of arc welding in maintenance such as pipe lines, railroad tracks, bridge strengthening, etc., not covered under L-1. |

# Certification of Papers for Award

The following is a copy of the Jury of Award's certification announcing the numbers of the papers selected to receive awards in the $200,000 Industrial Progress Award Program:

First Grand Award—Paper No. 515—
"Welded Caissons for Naval Dry Docks";

Second Grand Award—Paper No. 223—
"Redesigned 40 MM. Anti-Aircraft Gun Carriage";

Third Grand Award—Paper No. 100—
"Arc Welding Builds Higher Efficiency Mercury Arc Rectifiers".

Of the Class A Awards, the following awards are made:

| 1st | 2nd | 3rd | 4th |
|---|---|---|---|
| 648 | 427 | 415 | 700 |

Of the A sub-class Awards, the following awards are made:

| | 1st | 2nd | 3rd | 4th |
|---|---|---|---|---|
| A-1 | 652 | 334 | 420 | 46 |
| A-2 | 700 | 706 | 440 | 180 |
| A-3 | 427 | 415 | 526 | 304 |
| A-4 | 648 | 218 | 293 | 272 |

and Honorable Mention Awards as follows:

| | | | | | |
|---|---|---|---|---|---|
| A-1 | 116 | | | | |
| A-2 | 102 | 378 | 245 | 496 | 448 |
| A-3 | 566 | 372 | | | |
| A-4 | 705 | 474 | 593 | | |

Of the Class B Awards, the following awards are made:

| 1st | 2nd | 3rd | 4th |
|---|---|---|---|
| 708 | 730 | 558 | 469 |

Of the B sub-class Awards, the following awards are made:

| | 1st | 2nd | 3rd | 4th |
|---|---|---|---|---|
| B-1 | 469 | 424 | 653 | 247 |
| B-2 | 708 | 730 | 558 | 513 |

and Honorable Mention to the following:

| | |
|---|---|
| B-1 | None |
| B-2 | 518 |

Of the Class C Awards, the following awards are made:

| 1st | 2nd | 3rd | 4th |
|---|---|---|---|
| 153 | 173 | 570 | 550 |

Of the C sub-class Awards, the following awards are made:

| | 1st | 2nd | 3rd | 4th |
|---|---|---|---|---|
| C-1 | 570 | 37 | 332 | 82 |
| C-2 | 173 | 225 | 92 | 30 |
| C-3 | 153 | 550 | 260 | 638 |
| C-4 | 226 | 335 | 294 | 312 |

and Honorable Mention to the following:

| | |
|---|---|
| C-1 | 120 |
| C-2 | None |
| C-3 | None |
| C-4 | None |

Of the Class D Awards, the following awards are made:

| 1st | 2nd | 3rd | 4th |
|---|---|---|---|
| 305 | 508 | 147 | 240 |

Of the D sub-class Awards, the following awards are made:

| | 1st | 2nd | 3rd | 4th |
|---|---|---|---|---|
| D-1 | 305 | 508 | 147 | 540 |
| D-2 | 240 | 67 | 417 | 60 |

and Honorable Mention to the following:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| D-1 | 47 | 703 | 529 | 86 | 719 | 117 | 726 |
| D-2 | None | | | | | | |

Of the Class E Awards, the following awards are made:

| 1st | 2nd | 3rd | 4th |
|---|---|---|---|
| 515 | 698 | 155 | 555 |

Of the E sub-class Awards, the following awards are made:

| | 1st | 2nd | 3rd | 4th |
|---|---|---|---|---|
| E-1 | 549 | 452 | 33 | 709 |
| E-2 | 698 | 555 | 48 | 521 |
| E-3 | 580 | 739 | 431 | 437 |
| E-4 | 515 | 155 | 193 | 204 |

and Honorable Mention to the following:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| E-1 | 27 | 464 | 479 | | | | |
| E-2 | 510 | 694 | 14 | 136 | | | |
| E-3 | 186 | | | | | | |
| E-4 | 517 | 443 | 71 | 418 | 651 | 275 | 409 |
| | 645 | 128 | 202 | 207 | 277 | 87 | 553 |
| | 243 | 361 | 492 | 536 | | | |

Of the Class F Awards, the following awards are made:

| 1st | 2nd | 3rd | 4th |
|---|---|---|---|
| 235 | 257 | 716 | 276 |

Of the F sub-class Awards, the following awards are made:

| | 1st | 2nd | 3rd | 4th |
|---|---|---|---|---|
| F-1 | 235 | 276 | 595 | 535 |
| F-2 | 257 | 716 | 478 | 707 |

and Honorable Mention to the following:

| | | | |
|---|---|---|---|
| F-1 | 114 | 359 | |
| F-2 | 682 | 618 | 435 |

Of the Class G Awards, the following awards are made:

| 1st | 2nd | 3rd | 4th |
|---|---|---|---|
| 13 | 727 | 554 | 316 |

Of the G sub-class Awards, the following awards are made:

| | 1st | 2nd | 3rd | 4th |
|---|---|---|---|---|
| G-1 | 13 | 554 | 316 | 127 |
| G-2 | 727 | 113 | 576 | 216 |

and Honorable Mention to the following:

| | | | | |
|---|---|---|---|---|
| G-1 | 556 | 617 | 451 | 314 |
| G-2 | 125 | | | |

Of the Class H Awards, the following awards are made:

| 1st | 2nd | 3rd | 4th |
|---|---|---|---|
| 281 | 107 | 123 | 574 |

Of the H sub-class Awards, the following awards are made:

| | 1st | 2nd | 3rd | 4th |
|---|---|---|---|---|
| H-1 | 281 | 574 | 533 | 699 |
| H-2 | 107 | 123 | 701 | 560 |

and Honorable Mention to the following:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| H-1 | 208 | 481 | 406 | 362 | 350 | 244 | 704 |
| | 363 | 72 | 611 | 365 | | | |
| H-2 | 191 | 69 | 678 | 484 | 88 | | |

Of the Class I Awards, the following awards are made:

| 1st | 2nd | 3rd | 4th |
|---|---|---|---|
| 676 | 156 | 25 | 22 |

Of the I sub-class Awards, the following awards are made:

| | 1st | 2nd | 3rd | 4th |
|---|---|---|---|---|
| I-1 | 301 | 596 | 8 | 317 |
| I-2 | 676 | 156 | 25 | 22 |

and Honorable Mention to the following:

| | | | |
|---|---|---|---|
| I-1 | 76 | | |
| I-2 | 519 | 264 | 296 |

Of the Class J Awards, the following awards are made:

| 1st | 2nd | 3rd | 4th |
|---|---|---|---|
| 100 | 457 | 175 | 206 |

Of the J sub-class Awards, the following awards are made:

| | 1st | 2nd | 3rd | 4th |
|---|---|---|---|---|
| J-1 | 729 | 59 | 399 | 63 |
| J-2 | 297 | 433 | 157 | 434 |
| J-3 | 100 | 457 | 366 | 545 |
| J-4 | 206 | 20 | 326 | 646 |
| J-5 | 175 | 170 | 329 | 353 |
| J-6 | 84 | 280 | 58 | 547 |
| J-7 | 654 | 239 | 325 | Vacate |
| J-8 | 462 | 83 | 410 | 614 |
| J-9 | 45 | 439 | 221 | 634 |
| J-10 | 471 | 591 | 196 | 367 |

and Honorable Mention to the following:

| | | | | | |
|---|---|---|---|---|---|
| J-1 | 346 | 56 | 476 | 441 | 299 |
| | 338 | 198 | 583 | | |
| J-2 | 530 | 4 | 118 | 713 | 302 |
| | 590 | 604 | 470 | | |
| J-3 | 599 | 95 | 15 | | |
| J-4 | None | | | | |
| J-5 | 697 | 110 | 603 | 548 | 211 |
| | 507 | 49 | 612 | 425 | 39 |
| | 141 | | | | |
| J-6 | 29 | 139 | 702 | | |
| J-7 | None | | | | |

Honorable Mention *(Continued)*

| | | | | | |
|---|---|---|---|---|---|
| J-8 | 494 | 35 | 262 | 600 | 70 |
| | 666 | 261 | 143 | 172 | 400 |
| J-9 | 622 | 449 | 624 | 633 | 126 |
| | 565 | 205 | 660 | 356 | 137 |
| | 79 | | | | |
| J-10 | 308 | 736 | 491 | 212 | 621 |
| | 5 | 466 | 423 | 91 | 482 |

Of the Class K Awards, the following awards are made:

| 1st | 2nd | 3rd | 4th |
|---|---|---|---|
| 223 | 185 | 539 | 532 |

Of the K sub-class Awards, the following awards are made:

| | 1st | 2nd | 3rd | 4th |
|---|---|---|---|---|
| K-1 | 539 | 373 | 405 | 569 |
| K-2 | 532 | 187 | 259 | 99 |
| K-3 | 561 | 426 | 23 | 527 |
| K-4 | 185 | 347 | 105 | 459 |
| K-5 | 154 | 413 | 50 | 66 |
| K-6 | 551 | 650 | 159 | 64 |
| K-7 | 288 | 150 | 723 | 516 |
| K-8 | 543 | 655 | 16 | 220 |
| K-9 | 564 | 282 | 562 | 514 |
| K-10 | 223 | 217 | 454 | 291 |

and Honorable Mention to the following:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| K-1 | 189 | 307 | 511 | 98 | 528 | 525 | 538 |
| | 149 | 200 | 336 | 659 | 248 | 331 | 103 |
| K-2 | 93 | 266 | 340 | | | | |
| K-3 | 321 | 677 | | | | | |
| K-4 | 10 | 279 | 442 | | | | |
| K-5 | 487 | 559 | 572 | 523 | 327 | | |
| K-6 | 395 | | | | | | |
| K-7 | 65 | 695 | | | | | |
| K-8 | None | | | | | | |
| K-9 | 375 | | | | | | |
| K-10 | 287 | 402 | 573 | 44 | 379 | 541 | 349 |

Of the Class L Awards, the following awards are made:

| 1st | 2nd | 3rd | 4th |
|---|---|---|---|
| 531 | 419 | 649 | 267 |

Of the L sub-class Awards, the following awards are made:

| | 1st | 2nd | 3rd | 4th |
|---|---|---|---|---|
| L-1 | 419 | 267 | 658 | 534 |
| L-2 | 531 | 649 | 416 | 112 |

and Honorable Mention to the following:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| L-1 | 94 | 122 | 689 | 542 | 473 | 615 | 34 |
| | 354 | 687 | 68 | 460 | 453 | 342 | 53 |
| | 616 | 341 | 563 | 495 | 351 | 656 | 661 |
| | 711 | 552 | 219 | 12 | 444 | 450 | 1 |
| | 7 | 230 | 465 | 179 | 688 | 151 | |
| L-2 | 414 | 571 | 333 | 36 | 480 | 214 | 62 |
| | 360 | 237 | 285 | 134 | 370 | 269 | |

# Jury of Award

## Chairman

Dreese, E. E., Head of Department of Electrical Engineering,
The Ohio State University

## Jurors

Ahlquist, R. W., Assistant Professor of Electrical Engineering, Iowa State College

Andersen, Paul, Associate Professor of Structural Engineering, University of Minnesota

Butts, Allison, Professor of Electro-metallurgy, Lehigh University

Dowdell, R. L., Professor of Metallography, University of Minnesota

Dukes, R. G., Professor Emeritus of Applied Mechanics, Purdue University

Dwight, H. B. Professor of Electrical Machinery, Massachusetts Institute of Technology

Holtby, Fulton, Assistant Professor, Mechanical Engineering Department, University of Minnesota

Hughes, T. P., Assistant Professor of Mechanical Engineering and Assistant Superintendent of Shops in Mechanical Engineering, University of Minnesota

Koepke, C. A., Professor of Industrial Engineering, University of Minnesota

Macconochie, Arthur F., Professor of Mechanical Engineering, University of Virginia

Morris, Clyde T., Professor of Civil Engineering, Ohio State University

Muckenhirn, O. W., Instructor in Electrical Engineering, University of Minnesota

Taylor, Jacob B., Professor and Head of Accounting, Ohio State University

Van Hagan, L. F., Professor, Chairman of the Department of Civil Engineering, University of Wisconsin

Wright, Chilton A., Professor of Hydraulic and Sanitary Engineering, Polytechnic Institute

In addition to the above Jurors, experts or outstanding authorities in the various classifications covered by the Program were consulted as needed in order to properly appraise the merits of the papers.

# Chapter IV—Arc Welding of Magnesium Aircraft Structures

By VLADIMIR H. PAVLECKA and JOHN K. NORTHROP,
*Chief of Research and President, respectively,*
*Northrop Aircraft, Inc., Hawthorne, California.*

Vladimir H. Pavlecka

**Subject Matter:** The research work described has resulted in the development of a successful method of arc welding magnesium alloys in aircraft construction. A tungsten electrode is used in a stream of helium. Additional weld metal is fed from an uncoated electrode. The paper describes the design and fabrication of wings of "monocoque" type from magnesium alloy, for trainer planes.

John K. Northrop

**Monocoque Aircraft Structures**—During the last decade, monocoque, or semi-monocoque aircraft structures, in which all, or a substantial portion of the structure load, is carried in the skin, have come into general favor among airplane designers. A survey of modern aircraft finds few, if any, planes in which wings, fuselage, or tail structures are not substantially based on the stressed-skin principle, and many modern airplanes are almost solely dependent upon this principle for their long service life and rugged structural integrity.

Pioneered more than 25 years ago, the airplane fuselage fabricated from glued and nailed wooden strips was the first element in which the stressed-skin principle was used widely with success. Beginning within the last 15 years the same ideas have been applied with great advantage to steel, aluminum, and magnesium parts, while the newer synthetic binding resins have been utilized with excellent effect to improve the wood-base structures of the pioneers of monocoque.

The best and most efficient materials for use in pure monocoque construction are unquestionably those having low specific gravity and relatively high modulus of elasticity, in order that the material may have high compressive strength before buckling occurs. On this basis, certain plywood combinations, if uniform in quality and readily available in quantity, would no doubt prove of best structural value.

Unfortunately, however, nature controls the quality of tree growth, and the quantity is very severely limited by the number of suitable trees already in existence at a time of emergency. Those with sufficient summers to remember World War I can vividly recollect the shortage of suitable airplane lumber, and the resultant skyrocketing prices thereof, even as a result of the comparatively insignificant aircraft production of that day, and it is thought that even the most enthusiastic proponents of "plastic" (plywood) planes do not recommend their processes as applicable to more than a small portion of the present aircraft program.

On the other hand, metals are available (though rationed as to use) in

## aft Structures

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John K. Northrop

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very much larger quantities. Their qualities can be kept exceedingly uniform by comparison with those of a grove of trees, and production increases are dependent solely on men's energies and ingenuities.

**Stressed Skin Metal Aircraft Structures**—These facts led the authors, early in 1940, to choose the field of metals in a research program directed toward obtaining more efficient stressed-skin aircraft structures. While it was realized that the miracle of the organic chemist's test tube might one day produce a "true" plastic of outstanding physical qualities, nevertheless, the need was immediate, and there were available at hand metallic alloys having great promise.

In metals, as in other substances, low specific gravity in combination with high modulus of elasticity offered the most attractive field of research. Stressed-skin structures of steel have been commonplace in other fields of endeavor, but when designed to weight limits acceptable for modern aircraft, the result was almost always a comparatively thin sheet operating within its buckling range, and "stiffened" by a multitude of small formed beams, ribs, or stringers, spot welded or riveted to the main cover sheet. Here the cost of forming, handling, tooling and assembling becomes a serious if not prohibitive factor, although very efficient steel structures of a semi-monocoque type have been designed and built.

As the best known and most widely developed of the so-called light metals, aluminum and its alloys have come to be almost universally used for most external aircraft coverings.

Pioneered in European countries, at first largely to carry shear and torque loads as a wing and fuselage covering, aluminum has become within the last ten years an indispensable and major element in the designer's field of materials, and is used, reinforced by strips, extrusions, beads, or ribs, for the major portion of the structure on most military and transport aircraft that fly today. In the earliest examples, aluminum was used in corrugated form in an effort to increase the effective thickness, while later, smoother surfaces were demanded to reduce the excessive drag always related to external corrugated skin.

Flat aluminum sheet, however, must be regarded as having a higher density than desirable, and is rarely used without some internal stiffening strips or corrugations. Likewise, the comparatively thin cover sheets buckle within the range of normal-flight loads, as can readily be seen during a short ride in a modern transport. Also, while spot welding has been developed to an excellent degree of reliability for many of the aluminum alloys, an exacting technique is required in its use, and many joints must be made where the physical limits of spot welding equipment do not permit its use.

And so we find most modern aircraft to contain from 100,000 to over a million rivets, each requiring a layout, at least one and often two punching or drilling operations, and, in a majority of cases, the attention of two operators to drive. Then comes an individual inspection of each rivet which, if not successful, requires replacement and the expense and delays attendant thereon.

A further stimulus to the search for better, cheaper, and smoother aircraft structures lies in the fact that great advances in the science of aerodynamics have proven conclusively that the effects of rivet heads, (even if countersunk), local buckling, and general surface irregularities are much more detrimental than previously believed, and that the aerodynamic form of the external surface must be smooth, uniformly finished, and without local buckles if minimum drag is to be achieved.

**Magnesium Alloys**—All of the above consideration led, early in 1940, to a further investigation of available materials and methods of fabrication. As the lightest of generally available structural materials, magnesium and its alloys soon proved most attractive. Less than two-thirds of the weight of aluminum, and not much over one-fifth as heavy as steel, such materials have a relative stiffness, for a given weight of 2.5 times that of aluminum and 19.5 times that of steel.

First developed in the United States by the Dow Chemical Company as a relatively useless by-product, Dowmetal alloys have recently assumed greater and greater importance in the manufacture of aircraft. Available in cast, extruded, forged, and rolled form, these materials have first been used largely in engines, wheels, other accessories and secondary structures rather than in primary parts, although usage in Germany (where the comparatively greater availability has rendered magnesium especially attractive) has been more widespread than in the United States. The facts that the production of magnesium is rapidly expanding, that the sources are inexhaustible (9,000,000,000 pounds in each cubic mile of sea water), and that next to beryllium it is theoretically the best possible material for simple metal monocoque structures, have assured its widespread use in aircraft.

**Research on Fabrication**—Once a decision was reached as to the material choice, attention was at once turned to methods of fabrication. Magnesium had previously been spot welded and gas welded successfully. However, rivets of magnesium alloy work-hardened so rapidly during driving as to prove impractical, so that other materials had to be used for rivets in the assembly of magnesium parts. Also, the ideal surface smoothness for which we have been striving

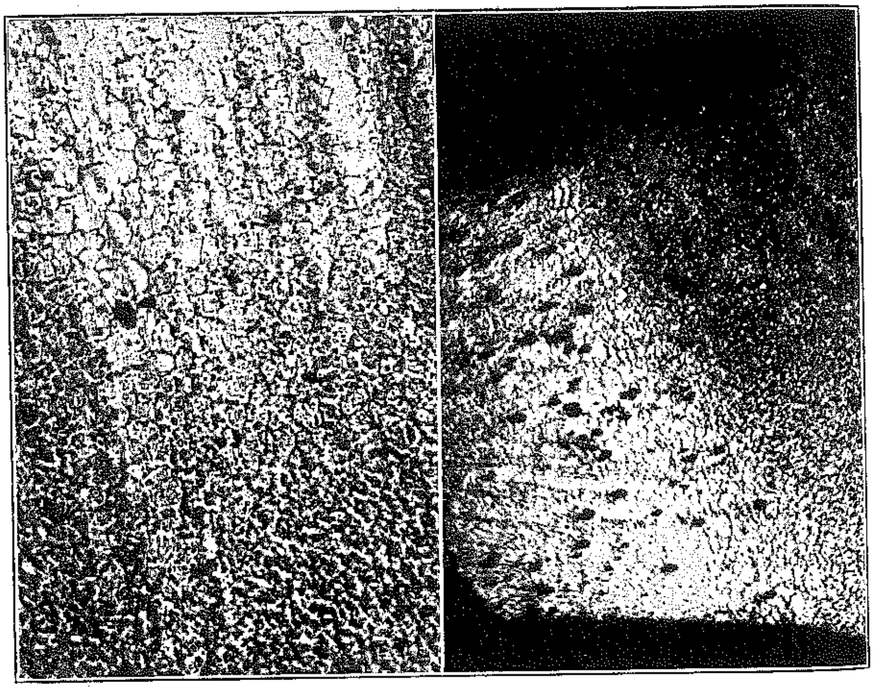

Fig. 1. Magnesium alloy arc welded. Left: Parent metal at top and weld metal at bottom. Right: Parent metal at left, weld metal at right.

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cannot be obtained by lap-joints, whether riveted or spot welded, particularly in view of the comparatively thick sheets which are employed in pure monocoque design. Gas welding was available as a means of attachment, but gas welding could only be accomplished under the protection of a heavy flux, due to the extreme affinity of magnesium for oxygen and nitrogen, particularly at elevated temperatures. And, unfortunately, the successful fluxes available were all of an extremely corrosive nature, and rapidly attacked the resultant magnesium assembly if the slightest contamination remained in the weld.

After many disheartening attempts, the path of research led finally to the consideration of electric arc welding which had previously been considered impossible on magnesium. The first experiments led to many small-magnesium fires. An amazing number of preliminary experiments can be imagined, when all possible variations in alternating and direct currents, polarity, types and materials for electrodes, fluxes, and blanketing gases were tried. It is the belief of the authors that all the unsuccessful combinations were attempted not once but many times. Fluxes were soon abandoned from considerations of corrosion, and numerous efforts were made to weld, using various types of blanketing gases either in an enclosed space, or allowed to flow over the work from the vicinity of the electrode. The first glimmerings of success occurred when the arc was struck between the work and a magnesium electrode which was supported in a hollow receptacle through which helium, under low pressure, was allowed to flow into the weld area. With this arrangement, however, the control of the flow of material to the weld was erratic and blobs of the electrode appeared in a disheartening array along the weld. Various refractory materials were then tried for the electrode, and when the research program reached the stage where a tungsten electrode was used in a helium atmosphere, success instantly crowned more than a year of experimentation and the "Heliarc" method of welding was born.

**Electric Arc Welding of Magnesium**—Basically, this method of electric welding, useful with all standard direct-current welding machines, consists in striking an arc between the work and a tungsten electrode, simultaneously feeding helium gas to the weld area through an annular nozzle surrounding the electrode, and feeding the additional weld material needed for the joint into the arc from an uncoated welding rod of substantially the same material as the work. Reversed polarity is used, that is, the current flows from the work to the electrode. The flow of helium, fed to the work area at .25 to .5 pounds per square inch, is controlled by a valve on the torch handle which is opened by the operator just before the arc is struck, and held open during the welding process. The arc is very quiet during a "Heliarc" weld, there is no tendency to sputter or throw materials from the weld as is sometimes the case with other processes, and a very uniform, high-quality weld can be obtained by an average operator after short practice. This method of welding will shortly be made available to the public under license, and while it was developed primarily for use on magnesium, it will probably find extensive use on alloy and stainless steels, where the results seem superior to those obtained by any other known method. The quality of the weld is high, the strength of the joint varying from 80 to over 100 per cent of the parent material, depending on the alloy and welding conditions, and there seems to be no limitation in the type of joint that can be made—butt, lap, tee, corner, and angle joints being made with equal facility.

The helium blanket completely eliminates the use of any flux in the joint, and while minute quantities of tungsten are present in the joint, there are no adverse corrosive effects therefrom. Actually, the weld appears somewhat more corrosion-resistant than the parent metal, there being a slight electrolytic balance which causes corrosion, if it appears at all, to be present in the sheet adjacent to the weld rather than in the weld itself. This effect is so small, however, as to be negligible for all practical purposes. Welds can be made with equal facility in rolled, cast, extruded, or forged parts, and some experiments have been made where cast and rolled or extruded parts have been welded to each other.

The seams, fusion welded by the "Heliarc" process, are distinguished by their metallurgical purity, homogeneity, and absence of inclusions. Fig. 1 shows a typical microscopic view of an etched "Heliarc"-welded seam in Dowmetal J-1 magnesium alloy. From it will be apparent the close-grained, highly-packed fused metal, which has approximately two per cent higher density than the parent metal, acquired in the welding process. It will be particularly noted that the fusion boundary is gradual and deeply penerating.

A typical torch assembly is shown in Fig. 2. Any good DC welding equipment is suitable for use in the "Heliarc" method, and the process has a particular attraction and importance in the United States, since our country is today the sole producer of this gas on a commercial scale and in large quantities, and also because considerable reserve volumes of it have been accumulated in the last six years.

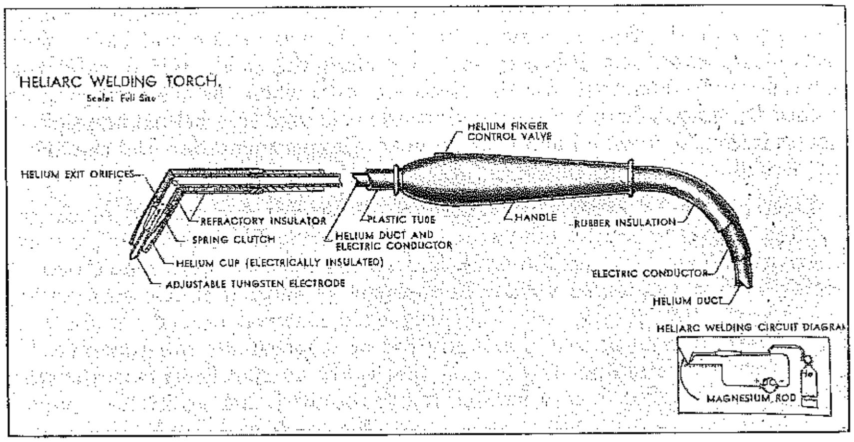

Fig. 2. Heliarc welding torch.

**Design Considerations**—Shortly after the first successful "Heliarc" welds were made a large number of samples were submitted to the Army Air Forces Material Center, for test and inspection. Complete checks, including fatigue tests, were made and the weld qualities appeared amply good to warrant an immediate program whereby a primary aircraft structure, assembled of magnesium alloys by electric arc welding, would be built. As a result, a contract for a number of airplane wings for Army Air Forces BC-1 trainer airplanes was given to this company early in 1941, and the design and development of these wings was begun at once, using Dowmetal J1-H alloy.

It was reasoned that the application of magnesium alloys to aircraft construction could be accomplished along two different principles. The first and most obvious way would be to design a magnesium airplane structure for maximum weight reduction. This conception was studied with the conclusion that the undesirable physical properties of magnesium alloys (rapid strain

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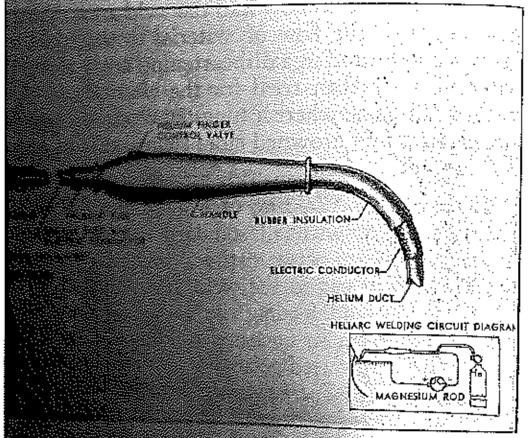

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hardening, corrosion, etc.) would probably not permit a greater weight saving than approximately 10 per cent over a comparable structure made of aluminum alloy. In view of the established fact that only approximately one-third of the weight of a modern military airplane empty is the airframe, or structural, weight, the total weight saving would, at best, amount to some 3.5 per cent of the empty weight of the airplane.

This slight gain was judged to be overbalanced by the necessity of an extremely careful and expensive design which would require the use of relatively thin gages of magnesium alloy sheet. It was therefore decided to favor, in the design of these wings, the perfection of the aerodynamic shape and simplicity and low cost of structural construction. These two qualities, in the estimation of the authors, are more important than small weight savings, provided they can be gained without increase of commonly accepted structural weights.

The design criterion adopted was, therefore, that superior and less costly magnesium airplane structures could be designed and built for the same weight as the present more expensive aluminum alloy riveted structures. The resulting design is shown in diagrams, Fig. 3 and Fig. 4.

**Design Applications**—The wing design illustrated was not made analytically by taking the weight of the present BC-1 aluminum alloy riveted wing and reapportioning it to the various structural components of the magnesium alloy wing. On the contrary, the "Heliarc" welded magnesium alloy wings were designed synthetically from the test experience and data already accumulated, and from the calculated loads acting on the wing. These considerations determined the proportions and distributions of the structural component parts and also the type of welding seams to be used in connecting them.

The calculated loads were based on the same design factors as used in the design of the riveted aluminum alloy wings already in service on BC-1 airplanes. Before the construction of the wings was begun, a very detailed weight analysis was made which indicated that the weight of the completed welded magnesium alloy wing structures should be approximately the same as that of the aluminum riveted wings. This has been approximately confirmed by actual weighing of the finished structures.

The BC-1 welded wings are designed on the semi-monocoque principle, with an internal structure, mainly for the purpose of maintaining form. The principal stresses, due to bending and shear, are carried directly in the thick, non-buckling outer shell. The guiding design idea of structural simplicity was carried out to the extreme and it can be safely stated that there is hardly a part in the structure of the welded wings which does not directly carry a portion of the flight load.

**Structural Details**—The whole wing structure is composed of only two basic elements: the sheet, forming the monocoque shell, and extruded sections, forming the internal structure. The versatility of arc welded construction made it possible to limit the number of various extrusions, such as "tees", angles, etc., to no more than four different sections. Furthermore, the preparation of the profile sections and sheets was greatly simplified, because flanges for riveting, and elaborate templates for the shaping of parts and the coordination of multitudes of rivet holes, were no longer necessary.

In order to provide ready access for inspection and repair, the wing was subdivided into two principal caissons by a span-wise, quickly-detachable grip joint on the upper and lower surfaces of the wing. This joint facilitates assembly and servicing, the latter being particularly important in a military

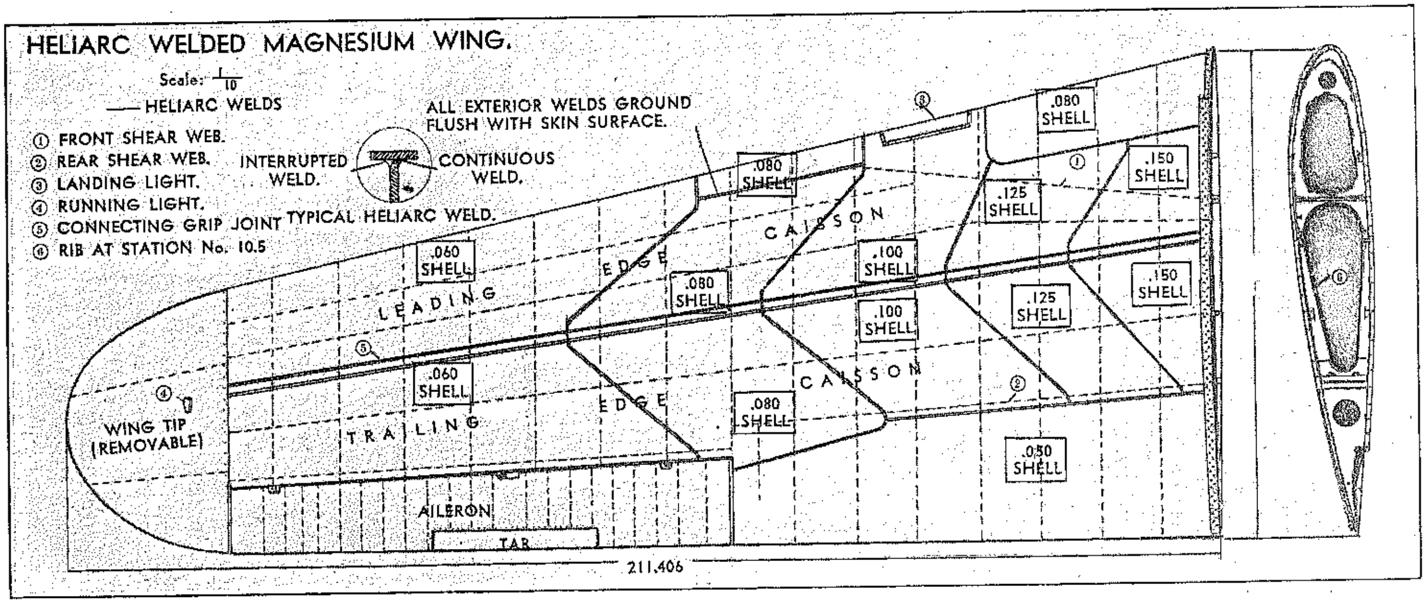


Fig. 3. Welded magnesium wing (top surface).

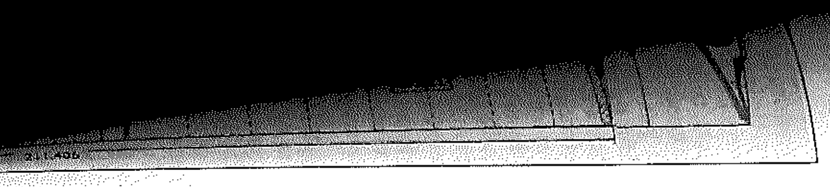


Fig. 3. Welded magnesium wing (top surface).

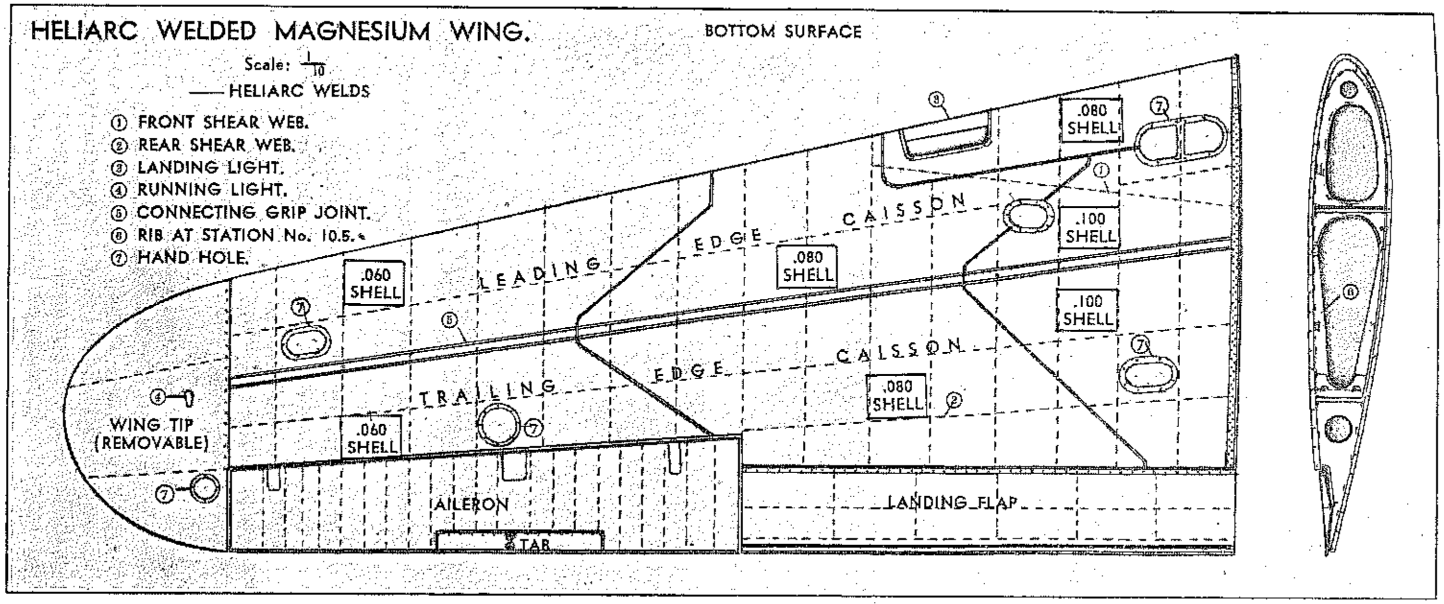


Fig. 4. Welded magnesium wing (bottom surface).

airplane. Fig. 5 shows the completed trailing edge portion of the wing. This caisson can be assembled in a few minutes with a similar leading edge portion into an integral load-carrying structure. On this structure there is fastened a "Heliarc" welded wing tip, Fig. 6, a welded landing flap, Fig. 7, and a welded aileron, Fig. 8.

The internal structures of the nose and tail wing caissons are shown in Fig. 9 and Fig. 10, respectively. These parts are built up of "tee" extrusions and sheet, welded into simple rib arch shapes having approximately the wing airfoil contour. This work is done on the bench in simple, adjustable jigs. The finished ribs are then welded onto the main shear webs and to the connector grip joints. This work is done in rotatable jigs, Fig. 11, and is easily accessible at all places where welding is required.

While the internal structure is being assembled, the monocoque shell panels are being prepared on a steel top bench. The wing root material thickness of the monocoque shell is .150 inch on the top and .100 inch on the bottom. These thicknesses diminish in steps toward the wing tip, where the wing shell is .060 inch thick on both top and bottom, as shown in Fig. 3 and Fig. 4. The butt seams between the sheets of the monocoque shell are scarfed and "Heliarc" welded at an angle of approximately 45° with respect to the principal stresses, so that the welds are subject mainly to shear stresses.

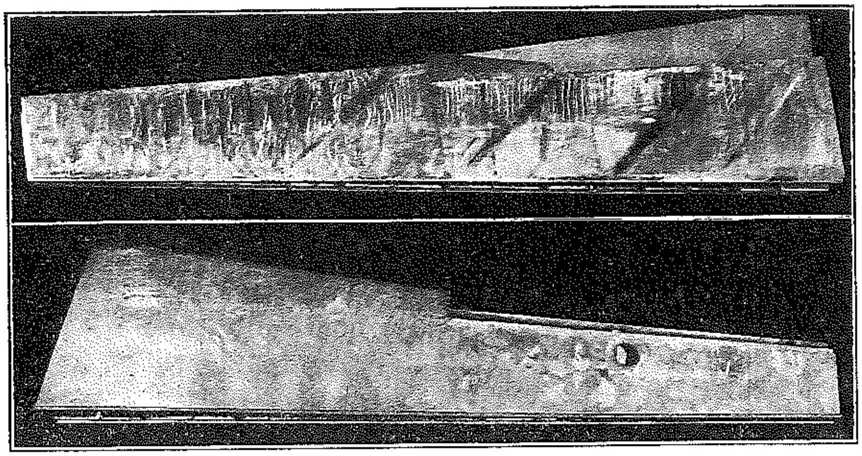


**Fig. 5. (Top) Highly polished surface ready for chemical treatment and (bottom) trailing edge caisson.**

The rib arches are designed with vertical stanchions at the connector grip joint, alternatively located on the nose and trailing edge caissons, Fig. 9 and Fig. 10. When dismantled, the wing caissons are held in shape by these vertical rib members while, when the wing is assembled, they act as spandrel columns which carry the crushing loads induced by the bending deflection of the wings.

The wing caissons are also equipped with supports and fittings for the controls of the ailerons and flaps, fittings for supporting the whole airplane on the ground from a jacking fixture, landing lights, electrical conduits, etc. All of these accessories are directly welded into the wing structure. External welds are smoothed over to the outer contour surface of the wing. All internal welds are left untouched except for brushing off the powder sediment after welding.

The inner structure, when complete and after inspection, is welded to the outer monocoque shell in jigs, Fig. 12. These jigs, as first designed, were rather heavy and complicated. Experience has shown that simpler and much lighter jigs would have been just as satisfactory and certainly cheaper and more convenient.

The wing structure also could have been designed on the "spanwise principle", that is by introducing spanwise stringers against the sheet and supporting them from a reduced number of ribs. The authors preferred the "chordwise" system here illustrated, as being structurally sounder and particularly because of its attractive characteristic of greater chordwise rigidity to resist compressibility loads that occur on modern wings of fast airplanes.

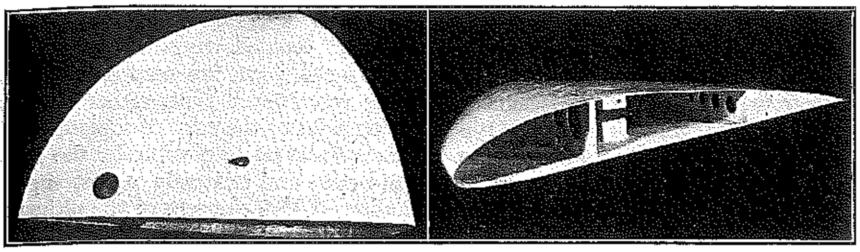


**Fig. 6. Welded wing tip assembly.**

**Manufacturing Problems**—In almost all welding, a certain amount of shrinkage distortion must be allowed for. Magnesium is no exception to this rule, and this phenomenon was the cause of some of the most persistent and annoying difficulties in the early stages of this development. A considerable number of tests led to making proper allowances in lengths for shrinkage and this difficulty was solved satisfactorily, as far as the dimensional control was concerned, at an early stage of the development. Sharp distortion due to shrinkage proved much more difficult to control. In structures of this nature, distortion manifests itself principally as buckling of the monocoque shell, particularly at those places where the curvature is not pronounced. However, there was developed a simple and satisfactory method of dealing with the buckling distortion, which does not harm the metal either internally or externally. This method has been used on the shell surfaces of the wings described in this paper, and by its use it is possible to obtain smooth, non-buckled surfaces after welding. By this method, heat and pressure are applied to the buckled structure through the use of ironing pads which relieve the internal strain in the sheet.

To make certain that no excessive locked-in strains are set up in "Heliarc" welded structures, experiments were carried out to obtain the absolute value of internal strains in magnesium alloys induced by welding. At the worst, these stresses were found to be of the order of 1000 pounds per square inch maximum, and are, therefore, of little consequence as far as the impairment of the integrity of "Heliarc" welded magnesium alloy structures is concerned. This is probably due to the relatively low modulus of elasticity and low yield strength of these alloys. Both of these physical properties tend to adjust the metal structure readily to any internally imposed strains from welding.

The amount of welding is not indiscriminate. Proportioning of the welded seams to the loads carried through them and selecting the type of weld to best fit the conditions of elastic flexure of the structure should be two recognized principles of electric arc welding application. It has been noticed that on a number of electric arc welded steel structures these principles have not always

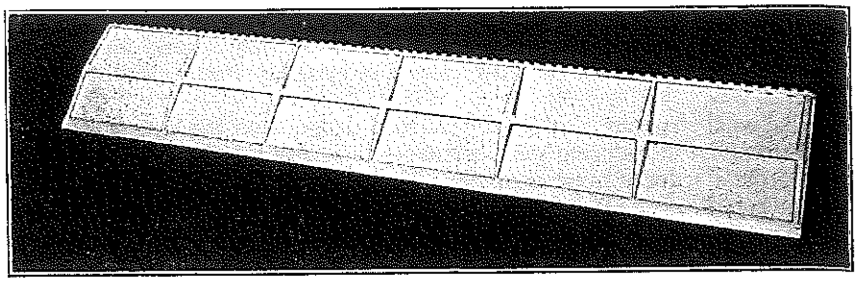


Fig. 7. Landing flap assembly.

been observed. The magnesium alloy "Heliarc" welded wings have been designed with great care in this respect. Full length seams are used only where necessary. Otherwise, the seams are of the interrupted type, either on one side, or of staggered interrupted type on both sides of the edge of a plate or of an extrusion attaching joint. These practices were made possible by the high metallurgical quality of the seams, their uniformly and relatively high strength. For design purposes, the Army Air Force allowed 75.9 per cent of the ultimate tensile strength of the metal to be used as the strength of the welded seams in tension. This figure is based on tests of seams made in the early stages of this development, and much higher uniform values are now being attained consistently as previously noted.

The wing tip and the aileron, (Figs. 6 and 8), were made of .050 inch thick Dowmetal J-1 annealed alloy. The reason that annealed metal was used for these two structures lies in the fact that loads on them are relatively low. Since .050 inch was self-imposed by the authors as the minimum practical sheet thickness of J-1 alloy for this design, it appeared that annealed metal could be used with safety and with the advantage that such material is delivered flatter than the equivalent gauge of the cold-rolled, strain-hardened J1-H sheet. Furthermore, the wing tips were formed to shape by drop hammering heated sheet (approximately 600°F.), which would have obliterated most of the cold-rolled strength of the J1-H alloy.

In point of accomplishment, the wing tips and the ailerons are even more noteworthy than the wings themselves. Both have already been tested for strength and found to be stronger than necessary and also more rigid than expected from past experience with comparable aluminum alloy riveted structures.

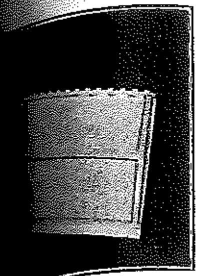
The utmost structural simplicity and the small amount of arc welding required to assemble the ailerons and the wing tips distinguishes these units as first class production articles.

The landing flap, Fig. 7, is an open structure, simple and easily accessible for welding. The same few structural elements are used in its assembly as on the wings.

The wings are attached to the airplane center section by riveted aluminum alloy flanges. This joint necessarily was copied from the aluminum alloy wings, because the arc welded wings have to fit, by exchange, a conventional riveted aluminum alloy airplane.

**Serviceability of Magnesium**—In the past, magnesium alloys have suffered from two generally known and popularly misunderstood faults. One is the general fear of their inflammability and the other is a deep-rooted and, by past performance, somewhat justified, conviction that these alloys corrode rapidly.

As to the first, the experience of the authors is that the fire hazard has



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been greatly exaggerated. In spite of the intensive welding development of these alloys in the shops during the last two years, the only fires involving magnesium were those started deliberately for test purposes, or in experiments before helium was used. It was discovered that the zinc chromate primer, generally used by the aircraft industry, acts as a potent fire inhibitor on magnesium, and that it is in fact impossible to ignite these alloys, even artificially, if they are protected by it. Magnesium retains its elastic modulus to much higher temperature than is the case with aluminum alloys. This is an extremely desirable property and in practice it means that a zinc-chromate-protected magnesium alloy structure will not collapse as readily as an aluminum alloy structure might do if exposed to fire.

The weather durability of magnesium aircraft structures in service is still undetermined. However, a wealth of artificial corrosion testing, and also gratifying results of the use of magnesium alloys on several truck bodies through a number of years, furnish convincing proof that corrosion is not as dangerous as is generally believed, provided proper surface protection is given. This protection consists of treating the finished, welded and cleaned structures with sodium dichromate and painting them with standard zinc chromate primer and two coats of finishing lacquer. This protection has been found to be sufficiently elastic under load, as well as abrasion resistant.

One of the least desirable physical characteristics of the magnesium alloys is their inclination to strain corrosion. The elasticity of the surface finish helps here a great deal but, in addition, the authors deliberately avoided stress concentrations in their design and saw to it that the maximum principal stresses anywhere in the wing remain low, viz. 12,600 pounds per square inch maximum in compression and 19,170 pounds per square inch maximum in tension.

Compared to the maximum allowable yield point in tension of 33,000 pounds per square inch for J1-H alloy, this utilization of the material seems wasteful. However, it was done deliberately in order to favor the rigidity of the outer wing shell, and also to diminish tendencies to strain corrosion. It is apparent, however, that as service experience is acquired it may be possible to design these structures for less weight than the equivalent weight of aluminum alloy riveted structures, without abandoning the non-buckling principle.

Static tests of magnesium wings have demonstrated that these wings are

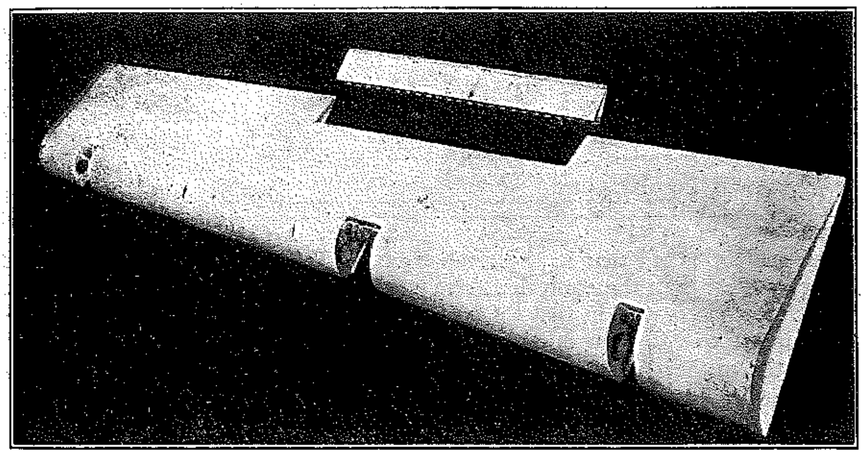

**Fig. 8. Aileron and tab assembly.**

elastically more flexible in bending than aluminum alloy wings. This is a desirable feature, as it tends to reduce excessive loads in gusty air, particularly when it is realized that the internal damping of magnesium alloys is several times greater than of aluminum alloys. On the other hand, the magnesium wings are more rigid in torsion than corresponding aluminum alloy riveted wings. This is also a very desirable property to eliminate danger from flutter, and can be traced to greater thickness, and to the absence of slippage in welded seams.

**Detailed Cost Comparison**—Dollar evaluation of the economic advantages of electric arc welding as applied to magnesium aircraft structures is a difficult task because of the many variables and intangibles involved. Direct comparison of the cost of a "Heliarc" welded seam and a riveted seam in the same materials is given hereunder:

**Table I—Comparison of Joint Cost Per Foot In .10 Sheet—Approximate Equal Strength**

| | | | |
|---|---|---|---|
| **"Heliarc" Welded** | | | |
| Surface preparation | .250 hrs. at | $0.97 per hr. | $0.24 |
| Setup | .083 hrs. at | .97 per hr. | .08 |
| Weld time | .100 hrs. at | 1.40 per hr. | .14 |
| Cleanup | .083 hrs. at | .97 per hr. | .08 |
| Helium 1 cu. ft. | | | .02 |
| Magnesium filler rod & tungsten electrode | | | .01 |
| Electric current | | | .01 |
| Total direct cost | | | $0.58 |
| Overhead on labor at 100% | | | .56 |
| Total cost per foot | | | $1.14 |
| **Riveted** | | | |
| Layout and drill 24 holes | .166 hrs. at | $0.97 per hr. | $0.16 |
| Countersink 24 holes | .10 hrs. at | .97 per hr. | .10 |
| Drive 24 rivets | .40 hrs. at | .97 per hr. | .39 |
| 24 rivets | | | .04 |
| Total direct cost | | | $0.69 |
| Overhead on labor at 100% | | | .65 |
| Total cost per foot | | | $1.34 |

It will be noted that in the comparison of Table I the weld is somewhat less expensive than the equivalent riveted joint. Such a comparison, however, is unduly conservative in that the cost of joining the parts is only a minor element in the overall economic gain to be made.

If the authors' philosophy is followed, namely, that welded magnesium structural design should be directed primarily to simplicity and aerodynamic excellence, it will be found that weights generally equivalent to those of contemporary structures of riveted aluminum alloy will be obtained. There is, therefore, little or no advantage from the standpoint of weight saving. On the

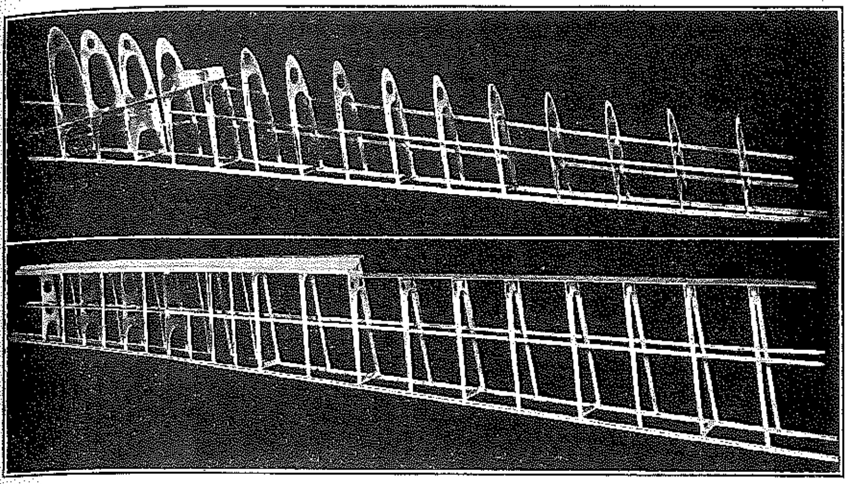

**Fig. 9, (above). Leading edge wing frame and Fig. 10, (below). Trailing edge wing frame.**

other hand, the reduction in number of parts for a given structure, and the possible reduction of drag of the finished airplane are factors of great importance.

The former advantage may be visualized to a limited extent by reference to Fig. 9. This photograph shows the complete internal structure assembly of the nose portion of the wing. All that remains to accomplish is the attachment by welding of the relatively thick cover sheet to the rib structure. A comparative check with a similar conventional structure indicates that the welded design has slightly more than one-half the number of feet of basic attachment of parts to each other employed in cases where riveted aluminum construction was used. In addition to this fact, the actual number of pieces required in the design is in the order of one-half the number required in the comparable aluminum alloy structure, so that the cost of fabrication may be expected to be reduced in similar measure. Unfortunately, at this writing the welded wings are only being produced in experimental quantities and no cost data on conventional wing structures in comparable quantities are available to the authors.

**General Economic Evaluation**—The actual structural cost, in itself, is still of minor importance in the overall economic advantage to be gained, however, because the most valuable contribution of this program lies in the possible reduction in drag of the finished airplane. Within the past few years a whole new family of high performance airfoils has been developed in which profile drag reductions of from 30 to 50 per cent have been obtained. These airfoils must be constructed with a degree of accuracy that is virtually impossible to obtain in conventional riveted structures which develop surface waves within the flight range. Monocoque welded magnesium structures, however, are readily adaptable to these requirements. They are designed with comparatively thick skins which do not buckle locally within the normal range of flight loads. Their surface finish can be as smooth as that of a fine automobile, and held within accurate limits. The outer surface of all welded joints may be ground flush with the face of the surrounding sheet so that no measurable inequality occurs at seams or joints. Butt joints and seams in the surface covering are a normal design procedure, so that laps as well as rivet irregularities and local buckling may be completely eliminated. Depending somewhat on cover thickness and internal structure, some slight surface irregularities may exist, but these, at the worst, can be limited to long waves of very low magnitude which do not adversely affect the drag of the structure. In summarizing this point, it may be said that a parasite drag reduction of at least 30 per cent may be obtained through the use of the new low-drag airfoils which, to the best of the authors' knowledge, can only be built to proper accuracy and finish in "Heliarc" welded magnesium, if metal is to be used.

Several extensive studies directed to the dollar value of aerodynamic improvement have been published in the past. One of these * has been selected as representative because it is written by competent personnel experienced in air transport operations and shows careful study of all operative factors in its preparation. To evaluate the direct effect of the possible saving in parasite drag under all conditions of speed, trip length, airplane size, first cost, etc., would require an additional paper longer than this one. However, a near approximation may be made for reasonably assumed conditions. The article referred to uses a modern four-motored transport having a parasite drag coefficient of .024 as an example. For a trip-length of 900 miles, (corresponding to a two-stop transcontinental flight), and an operating speed (block-to-block or station-to-station) of 250 miles per hour, the cost of transporting one ton of payload per mile is estimated as 30 cents. If the parasite drag is reduced 30 per cent to .0168, the cost per ton mile is reduced to 17.5 cents, evidencing a net saving of 12.5 cents. The payload for such a trip in the example airplane may be conservatively assumed to be 2½ tons, so that our gain in operating cost per mile of flight is 31.25 cents. We now multiply the saving per mile by the speed in miles per hour (250) and the reasonable life expectancy of the airplane of at least 15,000 hours, (many modern transports are charged off over a six-year period, which corresponds to nearly 20,000 hours), and we arrive at the rather staggering total of $1,172,000 per airplane. In the light of such figures, it may be seen that from a broad viewpoint it isn't particularly important whether the "Heliarc" weld costs more or less than the riveted joint, as the saving is about five times the total original cost of the airplane. The variation in cost between welding and riveting could be several hundred percent

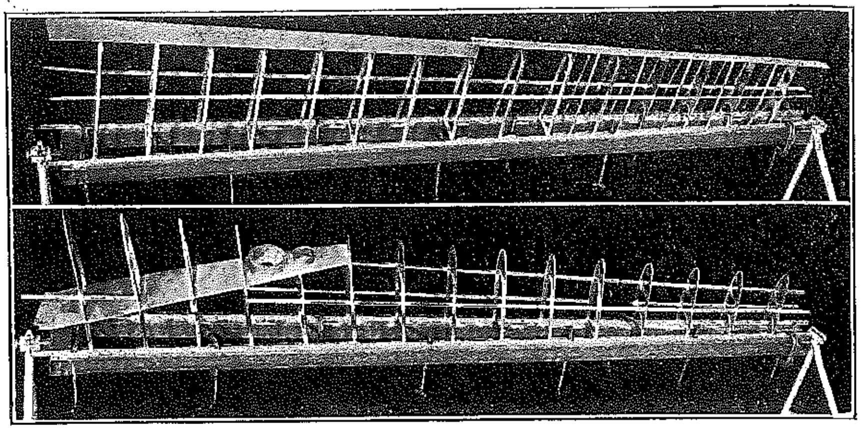

**Fig. 11. Trailing edge frame (above) and leading edge frame (below).**

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*"Some Economic Aspects of Transport Airplane Performance" by W. C. Mentzer and Hal E. Nourse. Jour. Aero. Sci., Vol. 7, pp. 227-234, 302-308 (1940)

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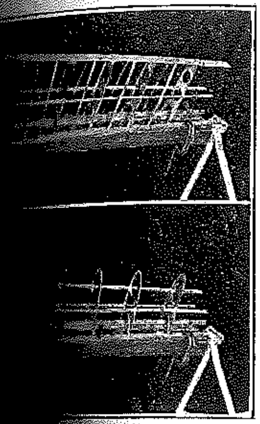

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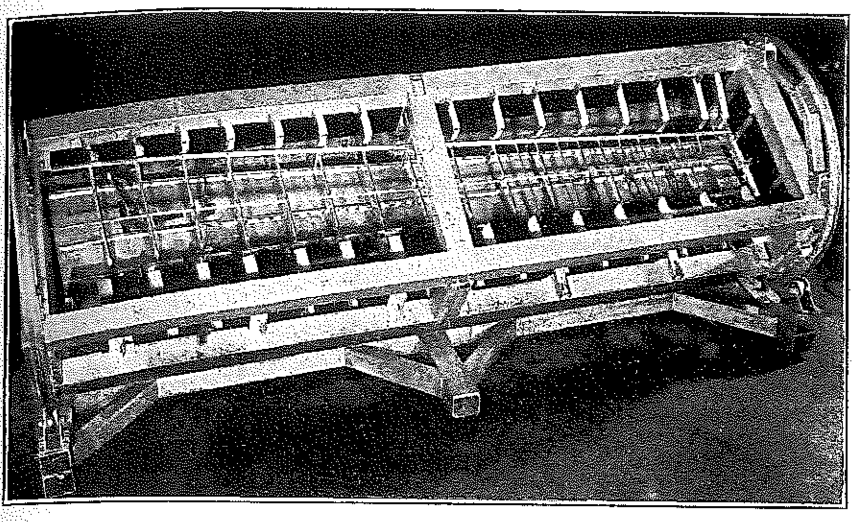

Fig. 12. Main wing jig trailing edge portion.

either way without greatly affecting the ultimate economic value of the aerodynamic gain involved. If we care to make one more step, and multiply the saving per airplane over its life by the approximate number of transports in operation in the United States prior to Pearl Harbor (say 400), the saving over the life of these ships is $468,800,000.

The above figures are conservatively based on modern four-motored transports of a type in use on American airlines in 1941. Recent airplane developments presage the day when aerodynamic refinements may greatly reduce the use of items contributing to the parasite drag, such as fuselage, tails, and engine nacelles. On the all-wing airplane of the future, the difference in drag between a conventional riveted aluminum airfoil and the low-drag wing made possible through magnesium "Heliarc" welded may be as much as 50 per cent. Leaving all other assumptions as they were, and for the same size airplane the saving per ton-mile becomes approximately 20 cents, the saving over the life of the airplane $1,875,000, and over the life of the 400-ship fleet, $750,000,000.

These figures are all based on a 900-mile trip. After the war is over, transports flying across the nation in eight to ten hours, and with only one stop, will soon go into service. On such longer hauls, the figures become even more impressive because the longer trips require a higher percentage of useful load to be devoted to fuel, and this increases the percentage of saving per ton-mile through reduction in drag, out of all proportion to the increase in trip length.

Truly, the United States, with an unlimited supply of sea water, and the only known large reserves of helium gas, is in an enviable position. Perhaps the green glow of the "Heliarc" is tinged with gold—or something even better—the power to serve mankind through an ever-increasing abundance of the things that make life worthwhile.