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ADVANCED ALUMINUM ALLOYS FROM RAPIDLY SOLIDIFIED POWDERS,

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Prepared by

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Sponsored by

Defense Advanced Research Projects Agency (DoD)

DARPA Order No. 3575

Monitored by
Air Force Materials Laboratory
Air Force Systems Command
United States Air Force
Wright-Patterson AFB, Ohio 45433

(15)

Contract No. F33615-78-C-5203, DARPA Order-3575
Effective 5 September 1978 to 5 June 1982

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ADVANCED ALUMINUM ALLOYS FROM RAPIDLY SOLIDIFIED POWDERS

Advanced aluminum alloys are to be developed that will provide major payoffs for important new aircraft, spacecraft, and missile systems in the next decade. Payoffs will result from weight savings of structural components which, in turn, lead to increased range, payload, service life, and decreased life-cycle cost. Recently conducted feasibility and design tradeoff studies provide a basis for selecting certain property goals for improved aluminum alloys that will result in significant weight savings. These property goals are:

A. Specific Elastic Modulus — 133×10^6 in.

B. Specific Elastic Modulus — 122×10^6 in., and
   Specific Yield Strength — 7.96×10^5 in.

Goal A is a 30-percent increase in specific modulus of elasticity relative to Al 7075-T76, without significant loss in strength, toughness, fatigue strength, or stress-corrosion resistance. Goal B is a 20-percent increase in specific modulus of elasticity accompanied by a 20-percent increase in specific strength, without significant loss in toughness, fatigue strength, or stress corrosion resistance.

1.0 OBJECTIVE

The objective of this program is to develop advanced aluminum alloys from rapidly solidified particulate that meet specific property goals. In addition, the program is to establish a metallurgical basis suitable for manufacturing scale-up and application to new weapon systems.

2.0 SCOPE

The program is divided into three phases, each consisting of a number of tasks. Phase 1 involves fundamental alloy development studies and consolidation process development and optimization. The most promising alloys are to be selected, produced in simple mill form, and evaluated in Phase 2. Phase 3 will consist of a design evaluation using the properties of the alloys evaluated in Phase 2.

This program was initiated in September 1978 and is scheduled for completion in 3-1/2 years. The effort during the first two years will be devoted to Phase 1 only. This report describes activity during the reporting period in each of the four tasks comprising Phase 1.

3.0 PROGRESS

3.1 Task 1 - Development of Alloys Containing Lithium

This task is being conducted by the Lockheed Palo Alto Research Laboratories (LPARL). An outline of Task 1 is given in Table 1.

3.1.1 Alloy Compositions

The first iteration of eight alloys contain 3 wt. % Li to meet program goal A of 30% increase in specific modulus; the compositions are given in Table 2. The rationale for selection of the alloy compositions was given previously (Ref. 1).

3.1.2 Generation of Splat Particulate

Argon atomized splat particulate was obtained from Alcoa for the eight first iteration Al-Li based alloys. The proprietary splat making process described in Section 3.2.2 was used. A total of 125 kg of material was obtained using the procedures outlined in Figure 1. Applicable production information is given in Table 3. Recovery levels from the nominal 28 kg starting Al-Li alloy melts were lower than anticipated, making it impossible to meet the delivery target of 16 kg for each alloy. Size limitations of the "special order" lithium-resistant crucibles precluded larger starting melt weights for these materials.

Recovery levels in the several attempts to produce the Al-1Zr-3Li alloy were exceptionally poor (8.4 kg total from three 28-34 kg starting charges). The very high melt temperatures ($\geq$ 1273°K) required to produce splat flakes of this corrosive alloy composition exceeded Alcoa's best current technology.

Zirconite-coated stirring, skimming and ladle transfer tools were rapidly consumed by the melt. Smoke and skim generation were excessive and sparks were intermittently observed in the argon gas atomized, molten metal spray pattern.

3.1.3 Characterization of Particulate

Actual Melt Compositions. Spectrographic analysis of each melt was obtained from samples removed from the pot furnace. Atomic absorption analyses and oxygen analysis by Fast Neutron Activation (FNA) are in process.

Screen Fraction Analysis. Results are listed in Table 4A for each splat run. All bulk materials were received by LPARL in the "as-splat" condition.

Cyclone Processing. A small 0.91 kg amount of cold "as-splat" flakes of alloy 1.1 were processed by Alcoa through a cyclone collection system normally used for atomized powder and air-processed splat flake production. The cyclone processing resulted in a beneficial reduction in plan area size of the larger splat flakes as shown in Table 4B. Chemical analysis of samples before and after cyclone processing verified there was no contamination from prior lots and no substantial increase in oxygen content. This cyclone system was not available for supplemental processing of bulk quantities in these first iteration alloys, but may be useful for subsequent lots.

Particulate Morphology. The splat morphology in alloy 1.6 (Al-3Li-1.5Mn) ranges from roughly circular to highly elongated flakes. One side of the flakes is flat (drum side), the other side is smooth or rippled. Atomized particles are found in screen fractions below 50 mesh. The atomized particles are rounded and have a dull grey colored surface and can be clearly distinguished from the splats which are flat and have bright shiny surfaces.

Surface Oxide Content. Preliminary results of Auger surface analysis on alloy 1.1 (Al-4Cu-3Li-0.2Zr) have shown the following. On splat particulate from the +8 screen fraction the oxide film thickness is 150-200 Å on both top and bottom (drum side) surfaces. The oxide film contains Al, Li and O; however the relative amounts have not yet been quantitatively determined. The amount of other elements in the oxide film is less than 0.1 at %. On particulate from the +100 screen fraction the oxide film thickness on splat particles is 50-100 Å and on atomized particles it is 150-200 Å.

According to Billman, CT-91 (formerly MA87) alloy atomized powder also has an oxide film thickness approximately twice that of splat particulate (Ref. 2).

Microstructure. Optical microscopy of alloy 1.1 (Al-4Cu-3Li-0.2Zr) reveals the thin flakes (~20μm) in the +30 screen fraction are predominantly free of dendritic structure and appear to show fine columnar grain structures. Similar columnar grain structures have been reported in the "splats" formed in atomized powder by the impact and solidification of one particle on the surface of another (Ref. 3). Thicker flakes (30-60μm) from the same screen fraction have dendritic structures of varying degrees of coarseness. Secondary dentrite arm spacings range from less than 1μm in flakes to greater than 10μm in atomized particles. Multiple layered splats were also observed.

3.1.4 Consolidation and Processing

Initial consolidations are being made using as-received un-screened particulate in order to establish baseline mechanical property data. The effects of screening and removal of atomized particles from the bulk lots of splat will be assessed later in the program. The particulate is consolidated by cold compaction to a packing density of about 40%, followed by vacuum degassing and hot pressing in a graphite lined steel die. After hot pressing to a density close to the theoretical value, the compacts are then extruded, using an extrusion ratio of 8:1. Preliminary metallographic examination of a 2 in dia hot pressed compact of alloy 1.1 (Al-4Cu-3Li-0.2Zr), vacuum degassed at 783°K and then vacuum hot pressed at 783°K using a pressure of 55 MPa, reveals very little porosity present, although some regions of poor interparticle bonding exist, especially around the atomized particles.

3.2 Task 2 — Development of Non-Lithium-Containing Alloys

This task is being conducted by the Alcoa Laboratories. An outline of Task 2 is given in Table 5.

3.2.1 Alloy Compositions

Compositions of the first iteration alloys, listed in Table 6, were derived from extensive data of Al-Fe-Ni-Co and Al-Mn-Si alloy systems showing promise for meeting improved stiffness and strength according to the contract goals. The rationale for selection of alloy compositions was given previously (Ref. 1).

3.2.2 Generation of Particulate

Both powder and splat particulate are produced using Alcoa's proprietary gas atomization technology.

In the fine atomized powder process, very small liquid droplets are generated by the interaction of high pressure atomizing gas with the molten alloy. These molten metal droplets are then cooled by high velocity room temperature air which continuously conveys them to a cyclone collection chamber. Preheated air was used as the atomizing gas species for these powder materials.

Alcoa's proprietary splat making process combines gas atomization with a single rotating quench drum. Atomized droplets are splat quenched against the rotating drum while they are still molten. Splat flakes rapidly solidify in this manner and then spall off the drum surface. Collection of the splat flakes may then be accomplished by either one of two methods: (1) batch collection in a relatively static room temperature air or "protective" argon gas ($\leq$ 6% oxygen) environment, or (2) continuous removal by high velocity room temperature air to the cyclone collection chamber. The various atomizing gas species used in this program for splat flake production included room temperature (cold) air or argon, and preheated air.

A total of 1086 kg of net product was obtained from twenty-two molten metal heats. Applicable production information is given in Table 7. Three atomized powder heats and three argon atomized splat heats were included for selected comparisons with the standard air atomized splat alloy materials.

3.2.3 Powder and Splat Particulate Characterization

Actual Melt Compositions. In accordance with standard P/M and Aluminum industry procedures, Alcoa uses melt chemistry as the best indicator of average particulate composition. Book mold samples were taken from the molten metal prior to atomization. These samples were used for preliminary spectrographic analyses, followed by atomic absorption determinations to obtain final compositions. Atomic absorption analyses and oxygen analysis by FNA are in process for the first iteration alloys.

Screen Fraction Analysis. Table 8 reports screen size results using conventional Tyler Ro-Tap equipment for random samples of each powder and splat particulate lot.

Except for alloy 2.1A, splat flakes produced with batch collection mode generally have significant weight fractions (>20%) in the coarsest +8 category. Splat produced with the continuous cyclone collection system have only 1-2 wt. % in the +8 screen fraction due to mechanical attrition in the high velocity air cyclone.

The fine atomized powder has over 90 wt. % in the -325 mesh (<44μm) size range with average powder diameters of 11.5 and 13.6μm in the two lots analyzed. This is indicative of atomization having successfully produced liquid metal droplets only 10-15μm dia which then solidified in flight.

Splat Particulate Morphology. The splat particulate morphology has been described as roughly circular flakes approximately 16-24μm thick, with one side of the flake being highly specular (drum side). Atomized powder exists in screen sizes below 200 mesh. The retention of solid solution was found to be diminished in particulate larger than 16 U.S. Standard Screen Size (Ref. 1).

Surface Oxide Content. Oxygen analyses by FNA are being obtained for representative lot samples of powder and splat particulate. Auger surface evaluation of selected particulate samples is to be initiated shortly.

Microstructure. Structural characterization of alloys 2.1A-2.4A, 2.6A and 2.7A (both powder and splat) is still in progress and will be reported subsequently. Guinier and optical characterization of alloy 2.8A was presented previously (Ref. 1). Comments regarding optical characterization of alloy 2.5A (splat) as well as initial transmission electron microscope (TEM) examination of both alloy 2.5A (splat) and alloy 2.8A (splat) follow.

Optical microscopy of alloy 2.5A splat (Al-9.68Mn) reveals both dendritic and non-dendritic structures, similar to that observed previously in alloy 2.8A splat (Ref. 1). It appears that a wide range of quench rates was experienced in both individual flakes and from flake to flake, a feature observed by other investigators (Ref. 4). One cause of varied quench rates in individual flakes in these alloys is an apparent variation in quench efficiency at the contact surface between the splat and quench drum. This apparent variation in heat transfer may be due to localized liberation on cooling of hydrogen dissolved in the liquid metal combined with the high melt viscosity which retards spreading of the droplet upon impact with the quench surface. More uniform quenching may be achieved by improved liquid metal degassing and additions to reduce melt viscosity.

Transmission electron microscopy of alloy 2.5A flakes from the +8 screen fraction shows the presence of relatively uniform dendritic structure having an average 0.64μm secondary dendrite arm spacing. This spacing corresponds to an estimated solidification rate of 10^6K/s (Ref. 5). Interdendritic precipitation is present, varying from an intermittent to a continuous film. A fine scale matrix precipitate is also present in some areas. These precipitates have not been identified yet, but are most likely $MnAl_6$.

Transmission electron microscopy of alloy 2.8A flakes from the +8 screen fraction shows the presence of a variety of dendritic and cellular structures. Secondary dendrite arm average spacings range from 0.17 to 0.3μm, corresponding to estimated solidification rates of 7×10^7 to 7×10^6 K/s. A fine scale, fibrous, interconnected structure with a spacing of ∿0.1μm is present within some primary dendrites and is believed to be the unidentified phase previously reported (Ref. 1). The fibrous structure is similar to features observed by other investigators in modified Al-Si alloys (Ref. 6) and in Al-Fe alloys (Ref. 4).

3.2.4 Phase Stability Studies

Work has been initiated on alloys 2.5A, 2.6A and 2.8A, with time intervals of 0.5, 5 and 50 hours at 575, 675 and 775K.

3.3 Task 3 - Quantitative Microstructural Analysis and Mechanical Property Correlations

This task will be performed by Georgia Institute of Technology. Activity will begin in June 1979 with the initial delivery of extruded material from LPARL.

3.4 Task 4 - Application Studies

This task is being performed by Lockheed-California Company.

3.4.1 Model for Prediction of Weight Saving

A Model was developed to predict weight savings in specific aerospace structures through substitution of advanced aluminum alloys for currently available aluminum alloys (Ref. 1). Application of this model will assist both alloy and process development to optimize payoffs in terms of weight savings and to evaluate sensitivity of payoff to variations in properties. Application of this model to the S-3A carrier based patrol aircraft has been previously presented (Ref. 1).

During this quarter the model has been adapted to an advanced tactical fighter (ATF) aircraft to permit assessment of effect on payoff and distribution of critical material properties. In addition, the effect of secondary structural criteria on payoff has been evaluated. This is important since all structure is designed to resist a variety of alternate critical failure modes. Although one set of (primary) criteria will generally size the structure, the next most critical set, described here as "secondary criteria" may limit the maximum payoff obtained from improvement of those properties that affect the primary criteria.

Adaptation of Model to Fighter Aircraft. The model was extended to include an ATF by determining the distribution of structural weight by critical design criteria. The aircraft selected for analysis is from the AF "Wing/Fuselage Critical Component Development Program." An aluminum version of a Boeing design concept, a delta wing Mach 2 Class fighter aircraft of 21,908 kg, gross weight, was selected (Ref. 7). Only the wing, tail, body and strake are considered here since the landing gear, nacelle and air induction system are primarily steel or titanium. The structural components considered weigh 6,273 kg, 81% of the total structural weight. An allocation of weight of individual components into the seven structural categories was then made by reviewing the loads and drawings available (Ref. 7) combined with prior applicable experience, see Table 10. This weight breakdown is considered reasonably representative of a variety of ATF types, independent of configuration, gross weight etc., for purposes of the present study.

As shown in Table 10, the ATF weight breakdown is similar to the S-3A. Weight savings in the ATF is less dependent on tensile strength, category 1, and more dependent on DADTA, category 7. The effect of elastic modulus on weight savings is similar for both ATF and S-3A, 56 and 59%, respectively. See Table 11.

Minimum Properties. The minimum DADTA (fatigue, crack growth and fracture toughness) properties required for compression critical structures, such as upper wing surfaces, were evaluated for various aircraft. The analysis indicated that tension and compression stresses in the upper wing surface could be increased by 22% for Patrol aircraft, 29% for transport aircraft and up to 50% for fighter aircraft before fatigue and crack growth properties become critical. Except for fatigue and fracture critical structure, the DADTA properties of current alloys are suitable for the advanced alloy requirements.

A sujmary of Engineering properties fo aluminum alloys exhibiting both satisfactory and marginal service experience in current and past aircraft systems is being compiled. These properties include strength, ductility, stiffness, fatigue, crack growth resistance, toughness and corrosion resistance. This information will provide a basis for establishing minimum acceptable properties when they are not dictated by conventional design analysis.

4.0 MAJOR ITEMS OF EXPERIMENTAL OR SPECIAL EQUIPMENT PURCHASED OR CONSTRUCTED DURING THE REPORTING PERIOD.

None.

5.0 CHANGE IN KEY PERSONNEL DURING THE REPORTING PERIOD.

None.

6.0 NOTEWORTHY TRIPS, MEETINGS, ETC. DURING THE REPORTING PERIOD

Meetings were held by the program manager with Alcoa personnel on May 11 and CALAC personnel on March 13 and May 30, 1979 to discuss ongoing technical activities regarding Phase 1 - Tasks 2 and 4, respectively. Meetings were also held on May 9, 1979 to interchange related technology with Dr. A. Rosenstein, AFOSR, and Dr. E. Balmouth, NAVAIR. On May 9, 1979, the program manager met with Dr. E. C. van Reuth, DARPA, to discuss plans for the next program review meeting. The tentative plan is for a 2-day meeting to be held at the Alcoa Technical Cneter on September 12-13, 1979. On May 14, 1979, the program manager was invited to present a short overview of the subject program to the NAS-NMAB Committee on Powder Aluminum Alloys.

7.0 SUMMARY OF PROBLEMS OR AREAS OF CONCERN IN WHICH GOVERNMENT ASSISTANCE OR GUIDANCE IS REQUIRED

None.

REFERENCES

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6. R. Elliot, "Eutectic Solidification," International Metals Review, Vol. 22, 1977, p. 161

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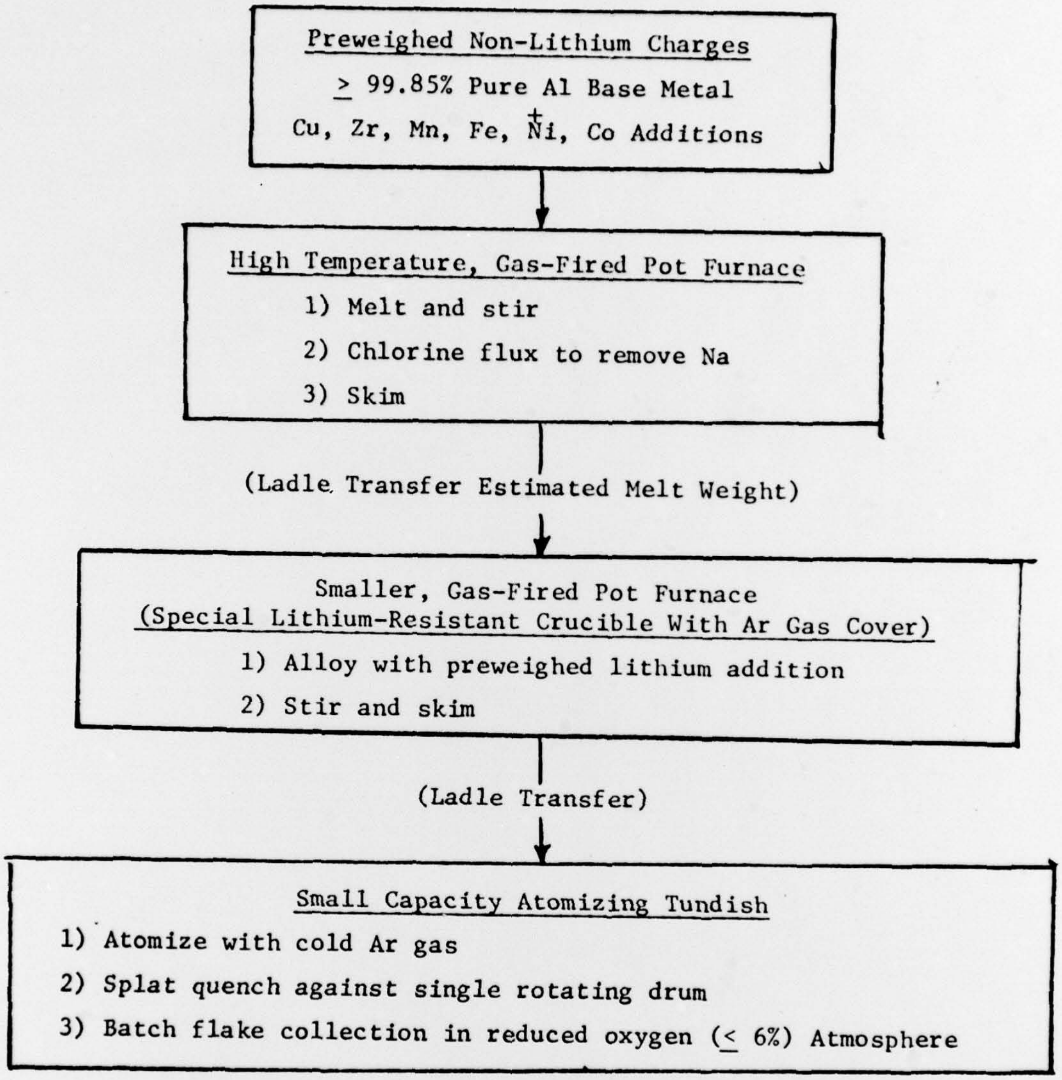

Figure 1. Al-Li Alloy Metal Preparation Steps

TABLE 1. DEVELOPMENT OF ALLOYS CONTAINING LITHIUM, PHASE 1 - TASK 1

- SELECTION OF ALLOYS
- FIRST ITERATION OF ALLOYS
- CHARACTERIZATION OF PARTICULATE
- CONSOLIDATION AND PROCESSING
- AGING BEHAVIOR
- STRUCTURE AND PROPERTY EVALUATION
- SECOND ITERATION OF ALLOYS
- SOLIDIFICATION PROCESS COMPARISON
- CONSOLIDATION PROCESS OPTIMIZATION
- SELECTION OF ALLOY/PROCESS FOR SCALEUP

TABLE 2. FIRST ITERATION OF ALLOYS CONTAINING LITHIUM

LPARL ALLOY DESIGNATION	TARGET MELT COMPOSITION (wt. %)
1.1	Al-3Li-4Cu-0.2Zr
1.2	Al-3Li-2Cu-0.2Zr
1.3	Al-3Li*-4Cu-0.2Zr
1.4	Al-3Li-4Cu-0.4Mn
1.5	Al-3Li-1Zr
1.6	Al-3Li-1.5Mn
1.7	Al-3Li-0.5Fe-0.5Ni
1.8	Al-3Li-0.5Fe-0.5Co

*Commercial Purity, all other alloys have high purity Li.

TABLE 3. PRODUCTION INFORMATION — Al-Li ALLOY SPLAT

LPARL ALLOY NO./ NOMINAL COMP.	Min. Melt Temp.(K)	Starting Melt Wt.(kg)	Amount Li Added(kg)	Net Wt. Splat(kg)	% Melt Recovery	Notes
1.1/ Al-4Cu-3Li-0.2Zr	1058	24.7	0.91	13.8	56	(a)
1.1X/ Al-4Cu-3Li	1023	29.5	0.91	19	64	(b)
1.2/ Al-2Cu-3Li-0.2Zr	993	29.5	0.91	15	51	(c)
1.3/ Al-4Cu-3Li-0.2Zr	1143	24	0.91	11	46	(a),(d)
1.4/ Al-4Cu-3Li-0.4Mn	1143	28	1.14	13.2	47	(a)
1.5/ Al-1Zr-3Li	1193	28	1.14	0	0	(a),(e)
1.5/ Al-1Zr-3Li	1143	28	1.14	2.8	10	(a),(f)
1.5/ Al-1Zr-3Li	1273	34	1.36	5.9	17	(a),(g)
1.6/ Al-1.5Mn-3Li	1173	28	1.14	16	57	(a)
1.7/ Al-0.5Fe-0.5Ni-3Li	1143	28	1.14	14.5	52	(a)
1.8/ Al-0.5Fe-0.5Co-3Li	1143	28	1.14	14.7	52	(a)

NOTES:
(a) Heated tundish.
(b) Unheated tundish. Zr charge addition omitted.
(c) Unheated tundish. Melt temperature somewhat low.
(d) Commercial purity Li
(e) Three attempts to atomize were unsuccessful.
(f) Inadequate melt temperature.
(g) Omitted special crucible step. Excessive skim generation and tool consumption.

TABLE 4. SCREEN FRACTION ANALYSIS RESULTS OF Al-Li ALLOY SPLAT FLAKES*

A. AS-SPLATTED

LPARL ALLOY NO./ NOMINAL COMPOSITION	Screen Size* - U.S. Standard (Wt. %) +8	-8 +16	-16 +30	-30 +50	-50 +100	-100 +200	-200 +325	-325
1.1/Al-4Cu-3Li-0.2Zr	11.2	35.8	19.2	15.4	9.1	6.6	1.4	1.0
1.1X/Al-4Cu-3Li	22.6	34.7	17.4	15.6	7.2	2.0	0.2	0.2
1.2/Al-2Cu-3Li-0.2Zr	17.4	45.2	19.8	11.4	3.2	1.6	0.6	0.6
1.3/Al-4Cu-3Li-0.2Zr	30.0	37.0	14.2	11.3	4.0	3.0	0.2	0.1
1.4/Al-4Cu-3Li-0.4Mn	21.0	43.0	19.4	10.2	3.8	2.2	0.2	0.2
1.5/Al-1Zr-3Li**	16.8	39.4	20.2	14.0	5.4	3.6	0.4	0.2
	14.4	39.6	18.4	16.4	5.4	4.8	0.4	0.4
1.6/Al-1.5Mn-3Li	12.2	23.8	18.0	19.0	10.6	11.2	2.8	2.2
1.7/Al-0.5Fe-0.5Ni-3Li	17.0	37.0	20.6	16.8	5.2	2.4	0.4	0.4
1.8/Al-0.5Fe-0.5Co-3Li	15.2	36.2	18.8	13.6	9.6	4.6	0.8	0.8

B. AFTER SUPPLEMENTAL CYCLONE PROCESSING

1.1/Al-4Cu-3Li-0.2Zr	0.6	18.2	18.4	17.4	14.4	15.0	7.6	8.2
Pct. Change Due to Cyclone Processing	-95	-49	- 4	+13	+58	+127	+443	+720

* Single, Random Sample

** Two Separate Melts

TABLE 5. DEVELOPMENT OF NONLITHIUM-CONTAINING ALLOYS, PHASE 1 - TASK 2

- ALLOY SELECTION (Two Systems-Four Compositional Variants Each)
- MANUFACTURE OF PARTICULATE (Eight 1st Iteration Alloys)
- POWDER AND SPLAT PARTICULATE CHARACTERIZATION
- DEFORMATION PROCESSING FUNDAMENTALS (Splat and Powder)
- PHASE STABILITY STUDIES
- HYDROGEN GAS EVOLUTION STUDIES
- FIRST ITERATION ALLOY SCREENING (Eight Splat Alloys)
- SECOND ITERATION ALLOY SCREENING (Two Systems-Two Variants Each)
- SELECTION OF ALLOY/PROCESS FOR SCALEUP

TABLE 6. FIRST ITERATION OF NONLITHIUM-CONTAINING ALLOYS

Alcoa Alloy Designation	Target Melt Composition (Wt. %)
2.1A	Al-3.27Fe-3.44Ni-3.45Co
2.2A	Al-3.27Fe-2.28Ni-4.59Co
2.3A	Al-3.27Fe-4.57Ni-2.29Co
2.4A	Al-4.27Fe-5.00Ni-5.03Co
2.5A	Al-9.68Mn
2.6A	Al-9.68Mn-2.47Si
2.7A	Al-4.95Mn-5.06Si
2.8A	Al-14.17Mn

TABLE 7. PRODUCTION INFORMATION — NON-LI ALLOY POWDER AND SPLAT PARTICULATE

Alcoa Alloy No./ Nominal Composition	Type	Min. Melt Temp. (K)	Wt. (kg)	Notes
2.1A/Al-3.27Fe-3.44Ni-3.45Co	Splat	1366	5	(1)
2.1A/	Splat	1366	48	(3)
2.2A/Al-3.27Fe-2.28Ni-4.59Co	Powder	1338	30	
2.2A/	Splat	1188	13.8	(4)
2.2A/	Splat	1310	123	(3)
2.3A/Al-3.27Fe-4.57Ni-2.29Co	Splat	1310	55.4	(3)
2.4A/	Splat	1310	41.8	(3)
2.5A/Al-9.68Mn	Splat	1310	30	(1)
2.5A/	Splat	1310	37.7	(1)
2.5A/	Splat	1199	24.1	(4)
2.5A/	Splat	1310	61.8	(3)
2.6A/Al-9.68Mn-2.47Si	Splat	1255	22.7	(2)
2.6A/	Splat	1255	66	(2)
2.6A/	Splat	1255	82	(2)
2.6A/	Powder	1144	158	(2)
2.6A/	Splat	1227	27.7	(4)
2.6A/	Splat	1310	58.6	(3)
2.7A/Al-4.95Mn-5.06Si	Splat	1310	50	(3)
2.8A/Al-14.17Mn	Splat	1255	33	(1)
2.8A/	Splat	1188	29.5	(1)
2.8A/	Powder	1310	24	
2.8A/	Splat	1310	64.5	(3)

NOTES:

(1) Cold air atomized splat. Batch collection without cyclone.
(2) Cold air atomized splat with cyclone collection.
(3) Hot air atomized splat with cyclone collection.
(4) Cold argon atomized splat. Batch collection without cyclone.
All Powder hot air atomized with cyclone collection.

TABLE 8. SCREEN FRACTION ANALYSIS RESULTS OF NON-Li ALLOY POWDER AND SPLAT FLAKES

		Screen Size* - U.S. Standard (Wt. %)								
Alcoa Alloy	Type	+8	- 8 +16	-16 +30	-30 +50	- 50 +100	-100 +200	-200 +325	-325	APD** μm
2.1A	Splat (1)	1.4	11.6	15.6	25.2	22.5	14.2	5.0	4.2	
2.1A	Splat (3)	1.4	10.0	11.2	18.5	7.4	15.6	10.8	25.0	
2.2A	Powder	0	0	0	trace	trace	1.6	4.4	93.8	11.50
2.2A	Splat (4)	33.4	29.2	13.8	13.6	2.4	6.0	0.6	0.8	
2.2A	Splat (3)	0.4	3.2	6.0	11.6	6.0	16.4	15.8	40.4	
2.3A	Splat (3)	2.2	11.0	10.0	15.6	10.6	14.2	10.0	26.2	
2.4A	Splat (3)	0.6	6.8	13.4	24.4	16.7	11.2	8.6	18.0	
2.5A	Splat (1)	21.8	26.2	14.8	19.0	11.1	5.4	0.8	0.8	
2.5A	Splat (1)	36.1	32.2	14.6	10.2	4.4	1.9	0.3	0.1	
2.5A	Splat (4)	24.8	43.8	18.2	9.4	2.4	0.8	0.2	0.2	
2.5A	Splat (3)	2.4	12.0	13.0	18.2	9.0	16.4	8.8	21.0	
2.6A	Splat (2)	3.4	38.0	28.8	20.4	12.8	4.2	1.2	1.0	
2.6A	Splat (2)	3.6	27.1	24.1	20.7	9.9	3.1	0.7	0.8	
2.6A	Splat (2)	2.8	26.6	25.5	25.5	12.7	4.7	1.2	0.8	
2.6A	Powder	0	0	0	trace	trace	2.2	6.2	91.4	***
2.6A	Splat (4)	28.0	40.0	18.6	9.4	0.4	2.8	0.4	0.4	
2.6A	Splat (3)	1.8	10.0	12.4	19.0	15.0	12.2	8.8	20.6	
2.7A	Splat (3)	2.6	12.6	13.0	18.4	6.6	21.2	9.2	17.0	
2.8A	Splat (1)	23.3	23.6	16.0	17.7	9.7	4.0	2.1	3.4	
2.8A	Splat (1)	27.0	35.0	18.0	14.0	4.0	1.0	0.5	0.5	
2.8A	Splat (3)	1.6	10.8	10.8	15.6	14.3	13.4	11.0	22.6	
2.8A	Powder	0	0	0	0	trace	1.4	5.2	93.3	13.60

NOTES:

(1) Cold air atomized splat. Batch collection without cyclone.
(2) Cold air atomized splat with cyclone colelction.
(3) Hot air atomized splat with cyclone collection.
(4) Cold argon atomized splat. Batch collection without cyclone.
* Single, Random Sample.
** Average powder diameter, determined with Fisher Sub-sieve sizer.
*** To be determined.

TABLE 9. ADVANCED TACTICAL FIGHTER WEIGHT STATEMENT

Aircraft Components	Weight (kg)	Percent of Gross Weight
Wing*	2938	13.4
Horizontal Tail	0	-
Vertical Tail*	427	1.9
Body & Strake*	2805	12.8
Landing Gear	935	4.3
Nacelle	170	0.8
Air Induction	475	2.2
Total Structure	7750	35.4
Total Propulsion	3671	16.8
Total Fixed Equip.	2265	10.3
Weight Empty	13681	62.5
Non-Exp. Useful Load	574	2.5
Operating Weight	14234	65.0
Payload	2345	10.7
Fuel	5330	24.3
Gross Weight	21909	100.0

*Aluminum components considered for weight savings analysis regarding advanced aluminum alloys.

TABLE 10. ALLOCATION OF WEIGHT BY FAILURE CRITERIA FOR ATF AND S-3A AIRCRAFT

Criteria Category	Criteria Description	ADVANCED TACTICAL FIGHTER Wing (kg)	Fuselage (kg)	Empennage (kg)	Control Surfaces (kg)	Total	Total (Wt. %)	S-3A PATROL PLANE (Wt. %)
1	Tensile Strength	499	544	54	68	466	18.6	30.1
2	Compressive Strength	91	113	18		222	3.5	-
3	Crippling	499	544	45	136	1225	19.5	14.3
4	Compressive Surface	249	222	91	45	608	9.7	8.1
5	Buckling	408	567	45	113	1134	18.1	19.7
6	Aeroelastic Stiffness	249	272	68	136	726	11.6	14.1
7	Damage Tolerance or Fatigue Cutoff	499	544	104	45	1193	19.0	13.7
Total		2495	2808	426	544	6273		

NOTE: Weights are based on aluminum structure in wing, tail, body and strake.

TABLE 11. PERCENT OF STRUCTURE AFFECTED BY SELECTED MATERIAL PROPERTIES

Property	Percent Aluminum Structure Affected	
	S-3A	ATF
Strength	52.5	51.3
Modulus	56.2	58.9
DADTA	13.7	19.0