Non-heuristic searches results:

Problem	Search used	# of node expansions	# of goal tests	Time elapsed	Optimal?
air_cargo_p1	Breadth_first_search	43	56	0.029	Y
air_cargo_p1	Depth_first_graph_search	21	22	0.013	N
air_cargo_p1	Uniform_cost_search	55	57	0.037	Y
air_cargo_p2	Breadth_first_search	3343	4609	7.990	Y
air_cargo_p2	Depth_first_graph_search	624	625	3.327	N
air_cargo_p2	Uniform_cost_search	4853	4855	11.527	Y
air_cargo_p3	Breadth_first_search	14663	18098	40.940	Y
air_cargo_p3	Depth_first_graph_search	408	409	1.735	N
air_cargo_p3	Uniform_cost_search	18223	18225	50.167	Y

A* search using three heuristics:

Problem	Heuristics used	# of node expansions	# of goal tests	Time elapsed	Optimal?
air_cargo_p1	h_1	55	57	0.037	Y
air_cargo_p1	h_ignore_preconditions	41	43	0.038	Y
air_cargo_p1	h_pg_levelsum	11	13	0.909	Y
air_cargo_p2	h_1	4853	4855	11.066	Y
air_cargo_p2	h_ignore_preconditions	1450	1452	4.032	Y
air_cargo_p2	h_pg_levelsum	86	88	176.399	Y
air_cargo_p3	h_1	18223	18225	54.401	Y
air_cargo_p3	h_ignore_preconditions	5040	5042	16.924	Y
air_cargo_p3	h_pg_levelsum	315	317	1072.356	Y

Heuristic Analysis:

From the table above, h_ignore_preconditions is the best heuristic. It produces optimal solutions for all three problems. It is the most balanced one – it expands a moderate number of nodes and goal tests while costs the least amount of time. It is better than non-heuristic searches for problems 2 and 3 in terms of number of nodes expanded, number of goal tests and time cost. However, it is not as efficient as BFS for problem 1 in terms of time cost, but still manages to find optimal solution by visiting fewer nodes and performing fewer goal tests.

Optimal solution for three problems:

Since all A* searches using different heuristics produce optimal results, all optimal solutions listed below are from A* search using h_pg_levelsum heuristic.

Problem 1:

```
Plan length: 6  Time elapsed in seconds: 0.9095049007010476
Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)
```

Problem 2:

```
Plan length: 9  Time elapsed in seconds: 174.04676084760476
Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Load(C3, P3, ATL)
Fly(P3, ATL, SFO)
Unload(C1, P1, JFK)
Unload(C3, P3, SFO)
Unload(C2, P2, SFO)
```

Problem 3:

```
Plan length: 12  Time elapsed in seconds: 1072.3556646924908
Load(C2, P2, JFK)
Fly(P2, JFK, ORD)
Load(C4, P2, ORD)
Fly(P2, ORD, SFO)
Load(C1, P1, SFO)
Fly(P1, SFO, ATL)
Load(C3, P1, ATL)
Fly(P1, ATL, JFK)
Unload(C4, P2, SFO)
Unload(C3, P1, JFK)
Unload(C2, P2, SFO)
Unload(C1, P1, JFK)
```

Problem 1 non-heuristic search metrics:

```
Solving Air Cargo Problem 1 using breadth_first_search...

Expansions   Goal Tests   New Nodes
    43          56         180

Plan length: 6  Time elapsed in seconds: 0.029081330140541272
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)


Solving Air Cargo Problem 1 using depth_first_graph_search...

Expansions   Goal Tests   New Nodes
    21          22          84

Plan length: 20  Time elapsed in seconds: 0.013019864945843326
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Load(C2, P1, JFK)
Fly(P1, JFK, SFO)
Fly(P2, SFO, JFK)
Unload(C2, P1, SFO)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Load(C2, P2, SFO)
Fly(P1, JFK, SFO)
Load(C1, P2, SFO)
Fly(P2, SFO, JFK)
Fly(P1, SFO, JFK)
Unload(C2, P2, JFK)
Unload(C1, P2, JFK)
Fly(P2, JFK, SFO)
Load(C2, P1, JFK)
Fly(P1, JFK, SFO)
Fly(P2, SFO, JFK)
Unload(C2, P1, SFO)
```

```
Solving Air Cargo Problem 1 using uniform_cost_search...

Expansions   Goal Tests   New Nodes
    55          57         224

Plan length: 6  Time elapsed in seconds: 0.03687856415940906
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)
```

Problem 2 non-heuristic search metrics:

```
Solving Air Cargo Problem 2 using breadth_first_search...

Expansions   Goal Tests   New Nodes
   3343        4609       30509

Plan length: 9  Time elapsed in seconds: 7.989823962204416
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Load(C3, P3, ATL)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)
Fly(P3, ATL, SFO)
Unload(C3, P3, SFO)
```

```
Solving Air Cargo Problem 2 using depth_first_graph_search...

Expansions   Goal Tests   New Nodes
   624          625          5602

Plan length: 619  Time elapsed in seconds: 3.327044069846668
Fly(P2, ATL, SFO)
```

```
Solving Air Cargo Problem 2 using uniform_cost_search...

Expansions   Goal Tests   New Nodes
   4853        4855       44041

Plan length: 9  Time elapsed in seconds: 11.527016752684148
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Load(C3, P3, ATL)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Fly(P3, ATL, SFO)
Unload(C1, P1, JFK)
Unload(C3, P3, SFO)
Unload(C2, P2, SFO)
```

Problem 3 non-heuristic search metrics:

```
Solving Air Cargo Problem 3 using breadth_first_search...

Expansions   Goal Tests   New Nodes
  14663       18098       129631

Plan length: 12  Time elapsed in seconds: 40.940392135499444
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P2, JFK, ORD)
Load(C4, P2, ORD)
Fly(P1, SFO, ATL)
Load(C3, P1, ATL)
Fly(P1, ATL, JFK)
Unload(C1, P1, JFK)
Unload(C3, P1, JFK)
Fly(P2, ORD, SFO)
Unload(C2, P2, SFO)
Unload(C4, P2, SFO)


Solving Air Cargo Problem 3 using depth_first_graph_search...

Expansions   Goal Tests   New Nodes
   408         409         3364

Plan length: 392  Time elapsed in seconds: 1.7354451236891109
```

```
Solving Air Cargo Problem 3 using uniform_cost_search...

Expansions   Goal Tests   New Nodes
  18223       18225       159618

Plan length: 12  Time elapsed in seconds: 50.16716919192517
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P1, SFO, ATL)
Load(C3, P1, ATL)
Fly(P2, JFK, ORD)
Load(C4, P2, ORD)
Fly(P2, ORD, SFO)
Fly(P1, ATL, JFK)
Unload(C4, P2, SFO)
Unload(C3, P1, JFK)
Unload(C2, P2, SFO)
Unload(C1, P1, JFK)
```

Problem 1 A* search using three heuristics:

```
Solving Air Cargo Problem 1 using astar_search with h_1...

Expansions   Goal Tests   New Nodes
    55          57         224

Plan length: 6  Time elapsed in seconds: 0.0368449662068941
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)


Solving Air Cargo Problem 1 using astar_search with h_ignore_preconditions...

Expansions   Goal Tests   New Nodes
    41          43         170

Plan length: 6  Time elapsed in seconds: 0.038059236328309265
Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)


Solving Air Cargo Problem 1 using astar_search with h_pg_levelsum...

Expansions   Goal Tests   New Nodes
    11          13          50

Plan length: 6  Time elapsed in seconds: 0.9095049007010476
Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)
```

Problem 2 A* search using three heuristics:

```
Solving Air Cargo Problem 2 using astar_search with h_1...

Expansions   Goal Tests   New Nodes
   4853        4855       44041

Plan length: 9  Time elapsed in seconds: 11.066255883347958
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Load(C3, P3, ATL)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Fly(P3, ATL, SFO)
Unload(C1, P1, JFK)
Unload(C3, P3, SFO)
Unload(C2, P2, SFO)


Solving Air Cargo Problem 2 using astar_search with h_ignore_preconditions...

Expansions   Goal Tests   New Nodes
   1450        1452       13303

Plan length: 9  Time elapsed in seconds: 4.032105523073698
Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)
Load(C3, P3, ATL)
Fly(P3, ATL, SFO)
Unload(C3, P3, SFO)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)


Solving Air Cargo Problem 2 using astar_search with h_pg_levelsum...

Expansions   Goal Tests   New Nodes
    86          88         841

Plan length: 9  Time elapsed in seconds: 176.3879245652451
Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Load(C3, P3, ATL)
Fly(P3, ATL, SFO)
Unload(C1, P1, JFK)
Unload(C3, P3, SFO)
Unload(C2, P2, SFO)
```

Problem 3 A* search using three heuristics:

```
Solving Air Cargo Problem 3 using astar_search with h_1...

Expansions   Goal Tests   New Nodes
  18223       18225       159618

Plan length: 12  Time elapsed in seconds: 54.40095428367734
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P1, SFO, ATL)
Load(C3, P1, ATL)
Fly(P2, JFK, ORD)
Load(C4, P2, ORD)
Fly(P2, ORD, SFO)
Fly(P1, ATL, JFK)
Unload(C4, P2, SFO)
Unload(C3, P1, JFK)
Unload(C2, P2, SFO)
Unload(C1, P1, JFK)


Solving Air Cargo Problem 3 using astar_search with h_ignore_preconditions...

Expansions   Goal Tests   New Nodes
   5040        5042       44944

Plan length: 12  Time elapsed in seconds: 16.924177989261835
Load(C2, P2, JFK)
Fly(P2, JFK, ORD)
Load(C4, P2, ORD)
Fly(P2, ORD, SFO)
Unload(C4, P2, SFO)
Load(C1, P1, SFO)
Fly(P1, SFO, ATL)
Load(C3, P1, ATL)
Fly(P1, ATL, JFK)
Unload(C3, P1, JFK)
Unload(C2, P2, SFO)
Unload(C1, P1, JFK)
```

```
Solving Air Cargo Problem 3 using astar_search with h_pg_levelsum...

Expansions   Goal Tests   New Nodes
   315         317         2902

Plan length: 12  Time elapsed in seconds: 1072.3556646924908
Load(C2, P2, JFK)
Fly(P2, JFK, ORD)
Load(C4, P2, ORD)
Fly(P2, ORD, SFO)
Load(C1, P1, SFO)
Fly(P1, SFO, ATL)
Load(C3, P1, ATL)
Fly(P1, ATL, JFK)
Unload(C4, P2, SFO)
Unload(C3, P1, JFK)
Unload(C2, P2, SFO)
Unload(C1, P1, JFK)
```