Raw data from run_search.py shows:

```
==============================================
****************first problem*****************
==============================================
Solving Air Cargo Problem 1 using breadth_first_search...
Expansions   Goal Tests   New Nodes
    43          56         180
Plan length: 6  Time elapsed in seconds: 0.06741007995344729
----------------------------------------------------------------------


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: 0.023054672229865264
--------------------------------------------------------------------------------


Solving Air Cargo Problem 1 using uniform_cost_search...
Expansions   Goal Tests   New Nodes
    55          57         224
Plan length: 6  Time elapsed in seconds: 0.057928661265964645
------------------------------------------------------------------------


Solving Air Cargo Problem 1 using greedy_best_first_graph_search with h_1...
Expansions   Goal Tests   New Nodes
    7           9           28
Plan length: 6  Time elapsed in seconds: 0.008321193128550015
--------------------------------------------------------------------
```

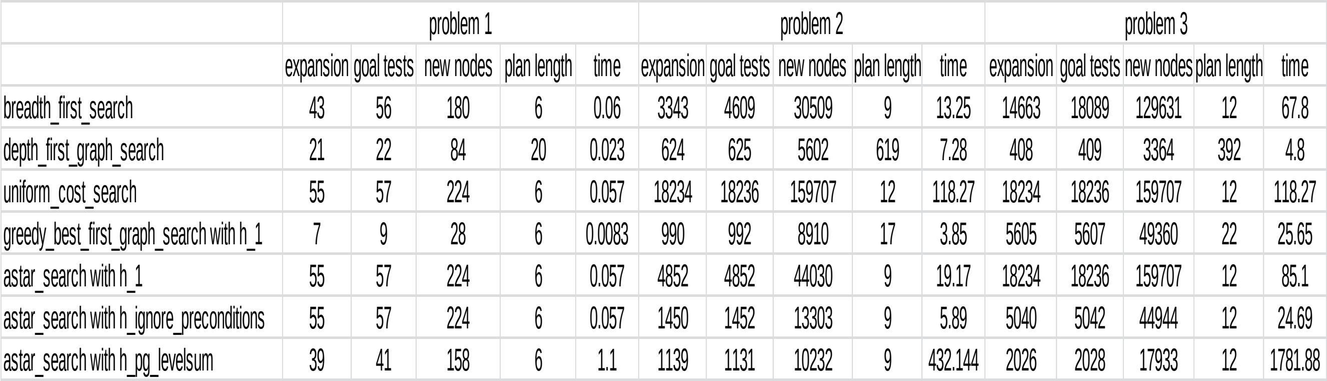
```
Solving Air Cargo Problem 1 using astar_search with h_1...


Expansions   Goal Tests   New Nodes

    55          57         224


Plan length: 6  Time elapsed in seconds: 0.05750736750927128

--------------------------------------------------------------------

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

Expansions   Goal Tests   New Nodes

    55          57         224

Plan length: 6  Time elapsed in seconds: 0.05828529848996208

-------------------------------------------------------------------

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

Expansions   Goal Tests   New Nodes

    39          41         158

Plan length: 6  Time elapsed in seconds: 1.1064087452578795

==============================================

****************second problem*****************

==============================================


Solving Air Cargo Problem 2 using breadth_first_search...

Expansions   Goal Tests   New Nodes

   3343        4609       30509

Plan length: 9  Time elapsed in seconds: 13.254542506282203

------------------------------------------------------------


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: 7.286895916837331


-----------------------------------------------------------------


Solving Air Cargo Problem 3 using uniform_cost_search...
Expansions   Goal Tests   New Nodes
  18234       18236       159707
Plan length: 12  Time elapsed in seconds: 118.27142042705127
---------------------------------------------------------------
Solving Air Cargo Problem 2 using greedy_best_first_graph_search with h_1...
Expansions   Goal Tests   New Nodes
   990         992         8910
Plan length: 17  Time elapsed in seconds: 3.857492383614393
----------------------------------------------------------------------------------
Solving Air Cargo Problem 2 using astar_search with h_1...
Expansions   Goal Tests   New Nodes
   4852        4854       44030
Plan length: 9  Time elapsed in seconds: 19.17898416376781
-----------------------------------------------------------------------------


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: 5.897049866094269
----------------------------------------------------------------------
Solving Air Cargo Problem 2 using astar_search with h_pg_levelsum...
Expansions   Goal Tests   New Nodes
   1129        1131       10232
Plan length: 9  Time elapsed in seconds: 432.1446043353745
```

```
==============================================
****************third problem*****************
==============================================
Solving Air Cargo Problem 3 using breadth_first_search...
Expansions   Goal Tests   New Nodes
  14663       18098       129631
Plan length: 12  Time elapsed in seconds: 67.86497047608248
-------------------------------------------------------------------------------
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: 4.802690840683738
-------------------------------------------------------------------------

Solving Air Cargo Problem 3 using uniform_cost_search...
Expansions   Goal Tests   New Nodes
  18234       18236       159707
Plan length: 12  Time elapsed in seconds: 118.27142042705127
------------------------------------------------------------
Solving Air Cargo Problem 3 using greedy_best_first_graph_search with h_1...
Expansions   Goal Tests   New Nodes
   5605        5607       49360
Plan length: 22  Time elapsed in seconds: 25.651536182770673
-----------------------------------------------------------------
solving Air Cargo Problem 3 using astar_search with h_1...
Expansions   Goal Tests   New Nodes
  18234       18236       159707
Plan length: 12  Time elapsed in seconds: 85.09576402212895
----------------------------------------------------------------------
```

```
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: 24.690193092116573

-------------------------------------------------------------------------

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

Expansions   Goal Tests   New Nodes

   2026        2028       17933

Plan length: 12  Time elapsed in seconds: 1781.885962297031
```

Summary:



	problem 1					problem 2					problem 3				
	expansion	goal tests	new nodes	plan length	time	expansion	goal tests	new nodes	plan length	time	expansion	goal tests	new nodes	plan length	time
breadth_first_search	43	56	180	6	0.06	3343	4609	30509	9	13.25	14663	18089	129631	12	67.8
depth_first_graph_search	21	22	84	20	0.023	624	625	5602	619	7.28	408	409	3364	392	4.8
uniform_cost_search	55	57	224	6	0.057	18234	18236	159707	12	118.27	18234	18236	159707	12	118.27
greedy_best_first_graph_search with h_1	7	9	28	6	0.0083	990	992	8910	17	3.85	5605	5607	49360	22	25.65
astar_search with h_1	55	57	224	6	0.057	4852	4852	44030	9	19.17	18234	18236	159707	12	85.1
astar_search with h_ignore_preconditions	55	57	224	6	0.057	1450	1452	13303	9	5.89	5040	5042	44944	12	24.69
astar_search with h_pg_levelsum	39	41	158	6	1.1	1139	1131	10232	9	432.144	2026	2028	17933	12	1781.88

Analysis

First let's talk about each problem optimal plan starting from problem 1:

1. Load(C1, P1, SFO)
2. Fly(P1, SFO, JFK)
3. Unload(C1, P1, JFK)
4. Load(C2, P2, JFK)
5. Fly(P2, JFK, SFO)
6. Unload(C2, P2, SFO)

Plan length: 6 steps

Problem 2 optimal plan:

1. Load(C1, P1, SFO)
2. Load(C2, P2, JFK)
3. Load(C3, P3, ATL)
4. Fly(P2, JFK, SFO)
5. Unload(C2, P2, SFO)
6. Fly(P1, SFO, JFK)
7. Unload(C1, P1, JFK)
8. Fly(P3, ATL, SFO)
9. Unload(C3, P3, SFO)

Plan length: 9 steps

Problem 3 optimal plan:

1. Load(C1, P1, SFO)
2. Load(C2, P2, JFK)
3. Fly(P2, JFK, ORD)
4. Load(C4, P2, ORD)
5. Fly(P1, SFO, ATL)
6. Load(C3, P1, ATL)
7. Fly(P1, ATL, JFK)
8. Unload(C1, P1, JFK)
9. Unload(C3, P1, JFK)
10. Fly(P2, ORD, SFO)
11. Unload(C2, P2, SFO)
12. Unload(C4, P2, SFO)

Plan length: 12 steps

The goal is to get the number of minimum actions to reach the goal, so in my opinion the optimal search algorithm must give us the least plan length.

For problem 1 “which had the least number of goals and preconditions”:

greedy_best_first_graph_search with h_1 is the optimal best search as it had the right plan length “minimum” and also the minimum time taken for execution, also the least number of goal tests and expansions which makes sense as this type of search starts with the node that is the nearest to the goal

For problem 2 and problem 3 “both have more conditions and goals than problem 1” :

greedy_best_first_graph_search with h_1 is still the algorithm recording the least time, depth_first_graph_search records the least number of goal tests and expansions which means less memory consumption, but both aren’t optimal “plan length of both is bigger than 9” which leads us to choose another search algorithm that is optimal with the least possible time for execution leading us to astar_search with h_ignore_preconditions

Comparing algorithms:

breadth_first_search: This is a good un-informed algorithm that takes suitable time to reach an optimal plan and I consider it as one of the best un-informed algorithm as it represent a balanced approach from the perspective of time, plan length and complexity "expansion and new nodes", as the BFS heuristic searches the each level for the needed target so when we have a lot of nodes and expansions this algorithm will prove useful, but when compared to informed algorithms specially to astar_search with h_ignore_preconditions, it loses.

depth_first_graph_search: This is one of the fastest algorithms :second fastest algorithm, as it searches in depth until reaching a goal, so it doesn't lead to un-needed expansions in each level, which leads to less complexity, but un-fortunately it doesn't give us the an optimal plan for our cargo transfer, so we can't use it.

uniform_cost_search: This an un-informed search algorithm and it isn't an optimal as it has more complexity than BFS and takes more time but reaches an optimal plan for cargo transfer

greedy_best_first_graph_search with h_1: This is the fastest algorithm and that is expected as it choses the node that is the nearest to the goal state using H_1 heurestic, so it takes less time to get to the goal and also it's the second algorithms in minimum number of nodes and minimum complexity but it doesn't provide an optimal cargo transfer plan, so we can't use it.

astar_search with h_1: This is also a good search algorithm that gives an optimal cargo transfer plan but BFS is better in all aspects "time, complexity and memory consumption"

astar_search with h_ignore_preconditions: This informed heuristic is superior to BFS in all aspects which is expected as it's an informed algorithm giving the optimal cargo transfer plan, so it's our best choice here

astar_search with h_pg_levelsum: This algorithm takes a lot of time and sometimes it timeouts so it can't be considered

Note that the best search algorithm is an informed search type and this is expected as according to Norvig and Russell's textbook at page 92:

'Informed search strategy—one that uses problem-specific knowledge beyond the definition of the problem itself—can find solutions more efficiently than can an uninformed strategy'[1]

SO it was expected that Astar search informed with h_ignore heuristic will be the best algorithm to choose

Summary:

DFS is the best algorithm from memory consumption point of view, greedy_best_first_graph_search is the least time consuming but both don't give us an optimized plan so the best algorithm here is the astar_search with h_ignore_preconditions as it's optimal and takes the least time and also less complex.

References:

- Video lessons from AIND
- Norvig and Russell's textbook ‘Artificial Intelligence A Modern Approach (3rd Edition)’[1]