Heuristic Analysis

A) Optimal plan

Air Cargo Problem 1

```
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)
```

Air Cargo Problem 2

```
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(C2, P2, SFO)
Unload(C3, P3, SFO)
```

Air Cargo Problem 3

```
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)
Fly(P2, ORD, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)
Unload(C3, P1, JFK)
Unload(C4, P2, SFO)
```

B) Compare and contrast non-heuristic search result

Air Cargo Problem 1

Search	Expansions	Goal tests	New nodes	Plan length	Time elapsed (second)	Optimal
breadth_first_search	43	56	180	6	0.064	Y
depth_first_graph_search	21	22	84	20	0.032	N
uniform_cost_search	55	57	224	6	0.080	Y

For problem 1, breadth first search and uniform cost search obtain the optimal plan. They only need 6 steps to reach the goal. However, finding the optimal plan requires more computation power. Depth first search only expands 21 of the nodes. And it uses 0.032 seconds to search. It is 2 times faster than breadth first search and 2.5 times faster than uniform cost search.

Air Cargo Problem 2

Search	Expansions	Goal tests	New nodes	Plan length	Time elapsed (second)	Optimal
breadth_first_search	3343	4609	30509	9	12.470	Y
depth_first_graph_search	624	625	5602	619	3.199	N
uniform_cost_search	4852	4854	44030	9	10.528	Y

For problem 2, the length of the optimal plan is 9. Breadth first search and uniform cost search find the shortest plan. But they need more number of node expansions compared with depth first search. (Breadth first search, depth first search and uniform cost search expands 3343, 624 and 4852 of the nodes respectively). The searching time of depth first search is the shortest. It needs 3.199 seconds. It is 3.9 times faster than breadth first search and 3.3 times faster than uniform cost search.

Air Cargo Problem 3

Search	Expansions	Goal tests	New nodes	Plan length	Time elapsed (second)	Optimal
breadth_first_search	14663	18098	129631	12	90.912	Y
depth_first_graph_search	408	409	3364	392	1.644	N
uniform_cost_search	18235	18237	159716	12	45.195	Y

The result of problem 3 is quite similar with previous two results. Breadth first search and uniform cost search obtain the optimal plan. They need 12 steps to reach the goal. But depth first search only expands 408 of the nodes and has the shortest searching time (1.644 seconds). It is 55.3 times faster than breadth first search and 27.5 times faster than uniform cost search.

C) Compare and contrast heuristic search result using A*

Air Cargo Problem 1

Search	Expansions	Goal tests	New nodes	Plan length	Time elapsed (second)	Optimal
astar_search h_ignore_preconditions	41	43	170	6	0.078	Y
astar_search h_pg_levelsum	11	13	50	6	0.971	Y

For problem 1, both heuristics obtain the optimal plan (i.e. 6 steps). “level-sum” heuristic only needs to expand 11 nodes. It is 3.7 times fewer than “ignore preconditions” heuristic. However, it is because “level-sum” heuristic requires more computation power. The searching time of “level-sum” heuristic is 0.971 seconds. It is much slower than “ignore preconditions” heuristic. (i.e. 0.078 seconds)

Air Cargo Problem 2

Search	Expansions	Goal tests	New nodes	Plan length	Time elapsed (second)	Optimal
astar_search h_ignore_preconditions	1450	1452	13303	9	3.805	Y
astar_search h_pg_levelsum	86	88	841	9	171.112	Y

Again, both heuristics obtain the optimal plan for problem 2 (i.e. 9 steps). “level-sum” heuristic expands 86 nodes in the search. It is 16.9 times fewer than “ignore preconditions” heuristic. But in term of searching time, “ignore preconditions” heuristic is better than “level-sum” heuristic. It only uses 3.805 seconds.

Air Cargo Problem 3

Search	Expansions	Goal tests	New nodes	Plan length	Time elapsed (second)	Optimal
astar_search h_ignore_preconditions	5040	5042	44944	12	15.757	Y
astar_search h_pg_levelsum	316	318	2912	12	844.695	Y

The result of problem 3 is quite similar with previous two results. Both heuristics obtain the optimal plan (i.e. 12 steps). “level-sum” heuristic need to expand 316 nodes. It is much fewer than “ignore preconditions” heuristic (i.e. 5040 node expansions). But the searching time of “ignore precondition” heuristic is better. It uses 15.757 seconds. It is 53.6 times faster than “level-sum” heuristic.

D) What was the best heuristic used in these problems? Was it better than non-heuristic search planning methods for all problems? Why or why not?

“ignore preconditions” heuristic was the best heuristic used in these problems. It is because it has the optimal plan and has the fastest searching time.
However, I am not sure that A* with “ignore precondition” heuristic is better than non-heuristic methods. It depends on the situations. For example, if searching time is critical, depth first search is the best method as it has the fastest searching time.
But if optimal path is an important factor, I will choose “ignore preconditions” heuristic.
Breadth first search and uniform cost search are guaranteed to find the shortest path. And “ignore preconditions” is an optimistic heuristic function and is able to find the lowest cost path. But the searching time of “ignore preconditions” heuristic is faster than breadth first search and uniform cost search. Thus, I will choose “ignore preconditions” heuristic when optimal path is an important factor.